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DESIGN AND IMPLEMENTATION OF A CFMA LOCAL AREA NETWORK -- PRIORITY NET

by

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A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled DESIGN AND IMPLEMENTATATION OF A CFMA LOCAL AREA NETWORK -- PRIORITY NET submitted by WILLIAM CHI-KEUNG FUNG in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE.

ABSTRACT

A network topology is described by the physical or geometric arrangement of the communication links and nodes that make up a network. Among these topologies, the bus (multipoint link) topology is the most attractive one because of easy configuration. Multiaccess bus structures can be divided into two groups, namely, *Collision-Free Multiple Access* (CFMA) and *Carrier Sense Multiple Access with Collision Detection* (CSMA/CD).

In this thesis, an experimental CFMA network named the Priority Net was implemented and has been tested at 1 Mbps (megabits per second), over a 56.4 meters coaxial cable. The Priority Net is a modified version of the CFMA Alberta Bus LAN which was invented by Dr. D. Zissos. However, the Priority Net can be extended to a distance of 0.5 Km since all the design calculations were based on that length. Every station has been assigned an 8-bit unique source ID according to a preselected priority and any station that contends for the bus in the contention window will send out its unique source ID. The system has been designed so that '1' overrides '0' in the contention window, thus lower priority stations need to backoff from the bus for higher priority stations. Since an 8-bit source ID is used, a maximum of 255 stations can be connected to the Priority Net.

An 8-bit microprocessor is used as the heart of the communication controller and the DMA (Direct memory Access) controller provides an interface between the channel and stations. Four stations have been implemented to run the different test programs and its unique access algorithm. Channel efficiency, average delay of accessing the bus and comparison with CSMA/CD Ethernet are also discussed. The work reported here also reviews the different families of local area networks and discusses some of the typical examples. Conclusion and future directions of local area network are also included.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

Km = kilometer

μsec = microsecond

ACRONYMS

Bit = binary digit

CATV = cable television

CCITT = Comite'Consultatif International de Te'le'graphique'et Te'le'phonique

CFMA = collision free multiple access

CSMA = carrier sense multiple access

CSMA/CD = carrier sense multiple access with collision detection

CRC = cyclic redundancy code

DCE = data circuit-terminating equipment

DTE = data terminal equipment

FCC = Federal Communications Commission

FDM = frequency division multiplexing

F/F = flip-flop

FSK = frequency-shift keying

GaAs = gallium arsenide

HDLC = high-level data link control

IMP = interface message processor

ISO = International Standards Organization

LAN = local area network

OSI = Open Systems Interconnection

PAM = pulse-amplitude modulation

PCM = pulse-code modulation

PWM = pulse-width modulation

Rx	=	receive
SDLC	=	synchronous data link control
Tx	=	transmit

SYMBOL

τ	=	single trip propagation time delay in seconds

TERMS USED IN THIS THESIS

Backoff signal	- a signal to indicate that a station with lower priority needs to give up its right to access the shared channel
Collision	- two or more stations transmit simultaneously such that their electrical signals are superimposed or in collision
Contention	- multiple users share a common link in a way that can lead to conflicts
Contention frequency	- the frequency at which the data stream can be used in the contention window
Dummy ID	- a special bit pattern, namely, 00000000 to indicate that it is the lowest priority
Ending flag	- a special bit pattern, namely, 01111110 to indicate the end of present transmission
Routing	- a software to decide which output line an incoming packet should be connected to
Source ID	- a unique bit pattern assigned to each station
Stripping	- for every five consecutive incoming 1's, followed by a 0 bit, then the 0 bit will be destuffed (deleted)
Stuffing	-for every five consecutive 1's in the data, a 0 bit will be stuffed in the outgoing bit stream
Transceiver	- an unit consists of transmitter and receiver

CHAPTER I

INTRODUCTION

1.1 LOCAL AREA NETWORK

Local area networks (LANs) are privately owned networks that offer reliable data communication channels in a limited geographic area. A local area network generally provides high-bandwidth communication over inexpensive transmission media. Local area networks are also called local computer networks because every node in the network is connected to computers (hosts) and terminals. Voice can also be integrated into a local area network and is a currently active research area.

Most of the terminology in network design follows from one of the first major networks, the ARPANET, however, there is still no precise definition that neatly describes all the characteristics of a local computer network. After much discussion, there is still considerable difference in the literature between a computer network and a distributed system. "Enslow's (1978) definition requires a distributed system to have a system-wide operating system, with services requested by name, and not by location. In other words, the user of a distributed system should not be aware that there are multiple processors, it should look like a virtual uniprocessor. In Tanenbaum's view, a distributed system is a special case of a network, one with a high degree of cohesiveness and transparency. In essence a network may or may not be a distributed system, depending on how it is used." [1]

Proposed techniques for local networks have drawn heavily upon the experience gained from the approaches used in processor interconnection as well as in long haul communication system. On the other hand, local network techniques are now influencing proposals for microprocessor interconnections , as well as long distance communication. Since the network services usually do not fall within the purview of any locally franchised communications common carrier - that is , the phone company does not maintain a monopoly on these services - the opportunities for experimentation and innovation in the development of local networks are greatly increased.

Typical application of distributed networks are as follows [2] [3] [4]:

i) A computer-based electronic mail system, in which messages between several hosts of a local area network can be exchanged.

ii) Access to specialized computing resources, occassionally required by the hosts of a local area network but too expensive to install locally.

iii) Transfer of files among computers.

iv) Application in distributed industrial control where a requirement of high speed reliable digital communication is required and the individual cell element control systems are supervised by a single computer station providing both control and management information.

v) Specialized multi-machine applications.

The communication traffic in LAN's is often described as being bursty, with short periods of intense usage followed by lengthy periods with low utilization. For this reason, information is routed in packet switching rather than traditional circuit switching approach. We would also expect that host machines would not communicate only with one other host, but would be exchanging packets with many different resources. With the present technology, most of the local networks tend to support data rates ranging from at least several kilobits per second (Kbps) up to many megabits per second (Mbps). The generic components of any local area network should consist of the following:

i) Communication Interface Unit (CIU) - which logically interfaces to the network.

ii) Media Access Units (MAUs) - which is the actual physical connections from CIU to the medium.

iii) Bus Interface Units (BIU) - which is the interface between the node's internal bus and the CIU.

iv) Network Nodes (stations) - which are the basic information-processing units, single and addressable entities, that are directly connected to a network.

The functions of each component will be described in the design issues of the Priority Net. Fig. 1.1 illustrates the geographic scope spanned by long-haul packet networks, local area networks, and computer system buses. "The shaded area of the long-haul network bar (from

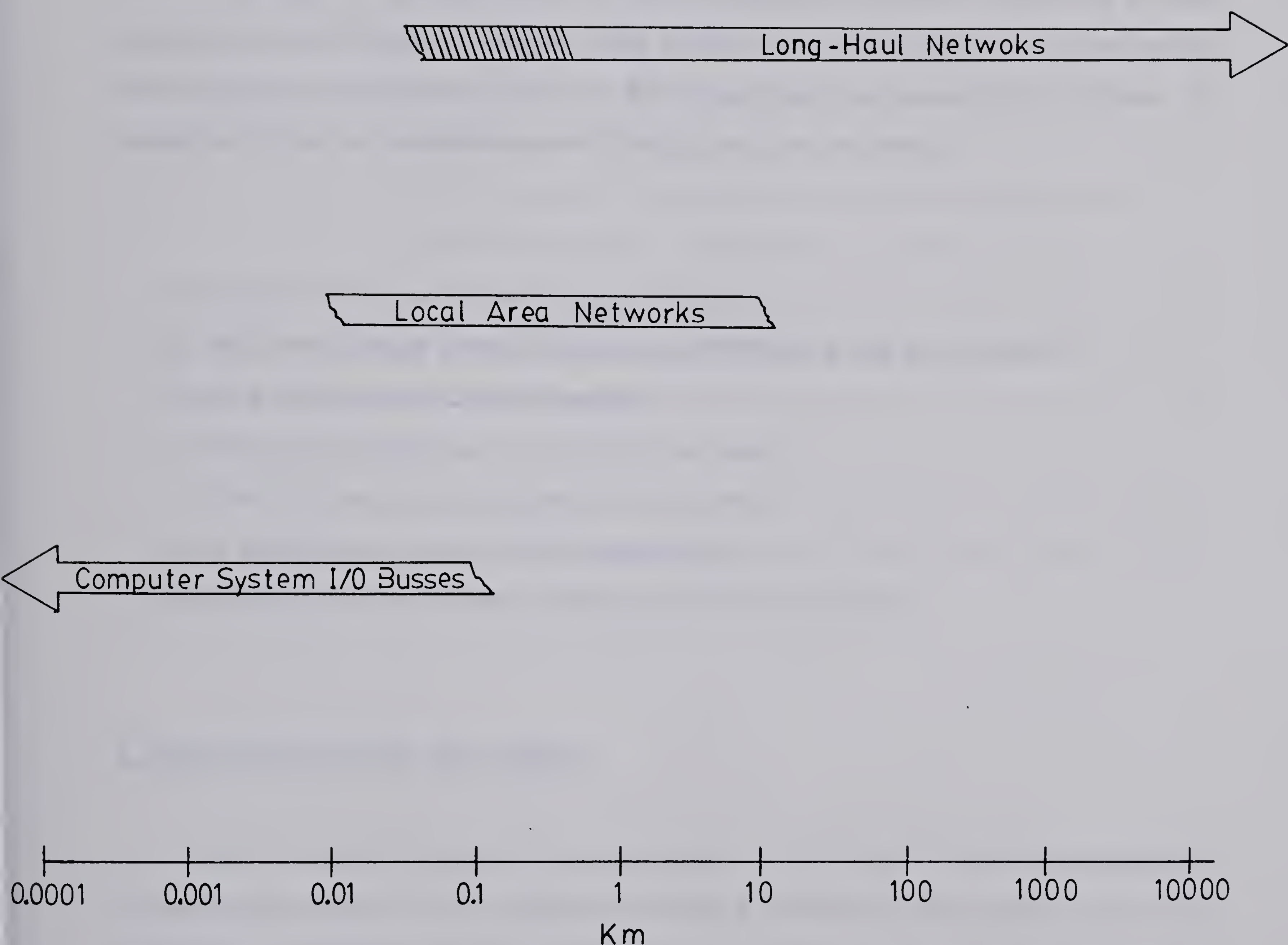


Figure 1.1 Geographic range of computer communication network and I/O buses. The shaded area of the long-haul network bar is explained in the literature. (Adapted from[5])

0.1 km to 2 km) indicates the distance range for which that technology has been used in the past, but which could be better served, in both cost and performance, by emerging local area network technology." [5]

1.2 THESIS OBJECTIVES

The first objective of this thesis is to examine several examples of multiaccess bus structures with and without collision. The second objective is to have a close look at some design issues of the Priority Net which is the Alberta Bus like LAN system. The Priority Net differs slightly in implementation from the Alberta Bus which was invented by Dr. Zissos. In keeping with these major objectives, the following points are considered

i) Why isn't a local area network merely a "big bus" ?
ii) What is the relation between a local area network and a long-haul network?
iii) How much total bandwidth is needed?
iv) What is the interconnectivity with other networks?
v) How many hosts can be supported on one network?
vi) Which designs are more efficient and reliable?
vii) How many hosts normally can be supported on one network?

1.3 ORGANISATION OF THE THESIS

The first half of this thesis mainly concentrates on the design of alternative architecture for local area networks. The second half will take a close look at the design issues of the Priority Net, a CFMA local network. Performance of different networks will be examined as well. The remaining chapters of this thesis have been organized as follows :

Chapter II discusses the alternative architectures for local networks e.g., topology, channel control, allocation and access. Different families of local area networks are also evaluated.

Chapter III deals with the analysis of multiaccess bus structure with emphasis on Ethernet-like CSMA networks.

Chapter IV describes the design, implementation and interfacing of the Priority Net. Criteria for avoiding collision to obtain a reliable channel is the major issue in this chapter.

Chapter V presents the channel efficiency of Priority Net with and without error separately. This chapter also looks at the Priority Net with respect to ISO model standard, average delay to access the channel, comparison with Ethernet and advantage of subnetworking.

Chapter VI discusses the conclusion on the experimental Priority Net and possible future directions in the field of local networks. The intergration of packet voice and manufacturing cells in local area networks are prominent topics in this chapter. Also, the major obstacle in network development and its huge commercial market are also discussed.

In addition to a list of references, a bibliography is included that gives a list of companies and their local networking products. The information is obtained from the paper published by Architecture Technology Corp., Minneapolis, Minn.. Each part in this section is prefaced with a structured guide to material, identifying related papers and providing a road map through the references.

Three appendices will be attached to this thesis describing the detailed circuitry diagrams, circuit layout, memory/IO map and some important demonstration subroutines (part of the operating system for the Priority Net).

CHAPTER II

ALTERNATIVE ARCHITECTURE FOR LOCAL NETWORKS

2.1 INTRODUCTION

Local area networks stemmed from both long-haul packet communication networks and I/O bus structures of digital computer systems; their structures and protocols are rooted in packet communication, while their hardware technology is derived from both networks and computer buses. Packet communication techniques have become well known and widely understood in the fourteen years since the start of the development of ARPANET in 1970. We will follow the terminology of one of the first major networks, the APRANET.

Development of a local area network is an exercise in design trade offs, because there are many different technological possibilities and alternative architectures.

2.2 CATEGORIES OF DESIGN ELEMENTS FOR LOCAL AREA NETWORKS

In the design of local area networks, we can identify at least five major categories that must be considered:

* Topology or physical connectivity.
* Addressing or logical connectivity.
* Switching technique.
* Transmission media .
* Point-to-point vs. broadcast channels.

The first four of these categories, specific topologies, switching techniques, control and access schemes, and transmission media are independent of one another. In theory, any control scheme can be used in conjunction with any access mechanism on any medium in any topological arrangement using any of a number of switching technique. The fifth one depends on the topology of the network.

2.2.1 *Topology* or Physical Connectivity

The *topology* of a communication system describes those stations which can communicate directly with each other, using the underlying media. There are two kinds of links that serve as the building blocks of network topologies.

A *point-to-point* link is a circuit which connects two and only two nodes without passing through an intermediate node, this is a fully connected topology. For n different nodes, n * (n - 1)/2 channels are required and twice that number of interfaces; note that there will be no need to share any of these channels.

A *multipoint* or multidrop link is a single line which is shared by more than two nodes. Multipoint lines can be used to reduce the number of lines required to connect nodes and to reduce line costs and therefore it is also referred to as a *partially connected topology.* Some means of controlling access or switching to the multipoint line must be implemented in order to avoid usage conflicts, since the line is shared by a number of nodes. Partially connected topologies can be further classified according to the particular topology.

i) *Unconstrained* topologies, in which their shapes are nonspecific and can be made up of a combination of point-to-point and multipoint links.

ii) *Star* or radial topologies, in which all the nodes are directly connected to one central point.

iii) *Ring* topologies, in which the nodes, which are connected by point-to-point links, are arranged to form an unbroken circular configuration.

iv) *Bus* topologies, in which a single line is shared by a number of nodes.

v) *Hierarchical* topologies, in which the physical connection forms a tree structure.

2.2.2 *Addressing* or logical connectivity

Addressing consists of control, allocation and access schemes which must be implemented in conjunction with network topologies to provide the performance and

operational characteristics desired for the intended applications of the local area network.

Control of the channel is either centralized in a single node or distributed to all the nodes.

Allocation schemes are implemented so that the capacity of the channel , which is finite, is used in the most efficient manner possible. Allocation involves specifying the amount of channel capacity or the amount of time that a user can have.

Access techniques are the means by which nodes actually gain the use of the common channel to transmit messages.

Suitable addressing and routing schemes can be used to provide the appearance of full logical connectivity even if the physical connectivity is less complete. Conversely, a system with very rich physical connectivity may have very restricted logical connectivity, if each node is only allowed to address a limited set of destination nodes.

2.2.3 Switching Techniques

When people are talking, it is unusual for gaps in the conversation to last for many minutes. When computers are communicating, such gaps are the rule, not the exception, so a fundamentally different type of switching is needed for data communication in order to achieve higher channel efficiency. The three major switching techniques used today are:

* Circuit switching
* Message switching
* Packet switching

Circuit switching, the predominent method used for establishing telephone connections is the basis of communications in telephone networks today. In circuit switching, every time a call is originated, the proper electrical path or circuit is established in the network to provide direct connection between the caller and destination.

An alternative switching strategy is *messasge switching* technique where no electrical path is established in advance between caller and receiver. Instead, when the caller has a message to send, it is stored in a switching office first, and then forwarded later. This

switching technique is also referred to as a store and forward technique.

Packet switching is developed as a solution to message exchange between computers. Packets are whole messages divided into discrete units of data. Packet switching is the process by which packets are placed on the channel and travel across the network to their destination. It is well suited to interactive traffic because no user can monopolize any transmission line for more than a few tens of milliseconds.

As shown in Fig. 2.1, circuit switching takes a long time to set up an end-to-end path before any signal can pass through and it is undesirable for computer applications. For packet switching, the first packet of a multipacket message can be forwarded before the second one has fully arrived, delay can be further reduced compared with message switching [1].

2.2.4 Transmission media

The transmission media provide the physical channel used to interconnect nodes in a network. Media are classified as bounded e.g., wires, cables and optical fibers; or unbounded e.g., air waves. The commonly used types of bounded media are:

Twisted-Pair wire, one of the original wire types used in telephone communications and it remains the main form of media in place for local telephone and data transmissions.

Coaxial cable, which offers large bandwidth and ability to support high data rates with high immunity to electrical interference and a low incidence of errors.

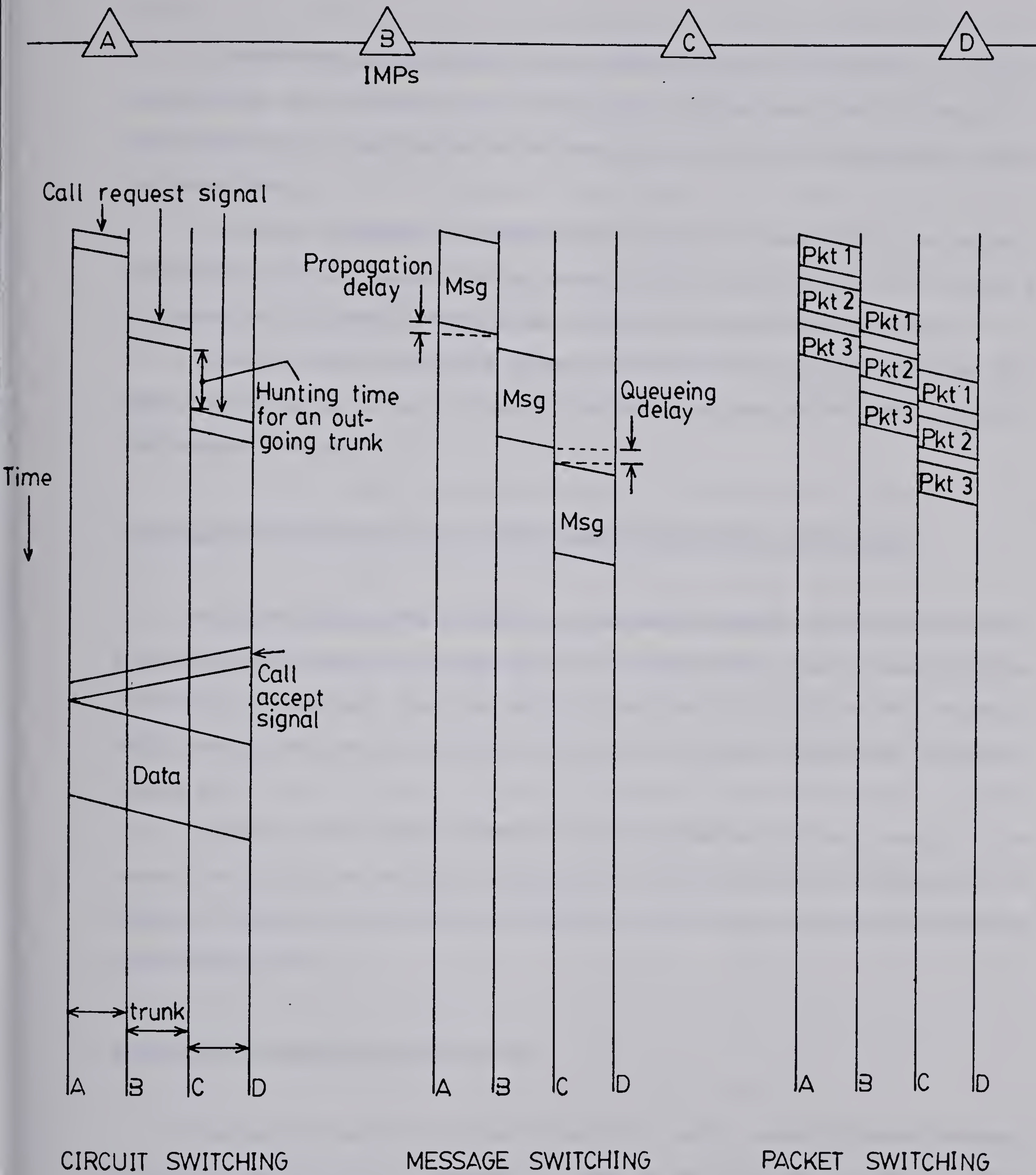
Optical fibers, which can serve as a very high performance transmission medium since the signals travelling in fibers are light waves and can have small attenuation and distortion.

More discussion on transmission media can be found in Chapter IV of this thesis.

2.2.5 Point-to-point vs. broadcast channels

Broadly speaking, there are two general types of designs for a communication channel, namely

* Point-to-point
* Broadcasting



Note: Adapted from [1]

Figure 2.1 Timing of events and efficiency in three different switching techniques

A *point-to-point* channel has only a single transmitter and a single receiver. To connect multiple hosts, these channels may be interconnected with the signal being regenerated at intermediate points or whole packets may be processed in a store-and-forward manner through intermediate hosts.

A *broadcast channel* allows multiple hosts to receive the same message simultaneously. The channel may only support a single transmitter and many receivers or it may be a multiaccess channel allowing different senders the ability to transmit to many receivers.

A point-to-point channel does guarantee reliable delivery to every destination since signal handshaking can be used. However, handshaking is more difficult for a broadcast communication channel.

2.3 A CLASSIFICATION OF THE MAJOR DESIGNS FOR LOCAL NETWORKS

In the following sections we will discuss five broad categories useful in describing local computer networks: store-and-forward systems, star configurations, rings, radio networks and multiaccess bus structures. Since the design of the Priority Net falls into the category of multiaccess bus structures, a more detail discussion of this specific network can be found in Chapter III.

Although we can identify these five major approaches that have emerged in the construction of local area networks, each occupies a different region in the design space. A decision to choose one of these approaches will restrict the alternatives available with respect to other design decisions.

2.3.1 Partially connected, store-and-forward

This approach uses point-to-point channels in a partially connected physical topology, for example, the ARPANET. Connectivity is based on interconnected nodes with no central control. Full logical connectivity can be provided by switching the individual packets through the intermediate nodes until they reach the appropriate destination. In other words, packets that are to be sent from one host to the other are first received and stored at the intermediate

node and forwarded when the required output line is free. In order to respond to changes in connectivity, this system requires some form of dynamic routing procedure.

There are basically two variations on this theme, distinguished by the place in which the packet switching software is run: store-and-forward via IMPs or store-and-forward via hosts.

a) The first variation, for example the ARPANET, uses a separate packet switching node (an Interface Message Processor, or IMP) connected to each host. The IMP is a specialized computer which does most of the packet processing and handles all the routing procedures. This approach has the attractive feature that the network continues to function even if individual hosts are unavailable. For connecting small computers in a local network, however, the cost of a packet switching node may be roughly equal to the cost of the host itself, and this may be economically unattractive.

The USC (University of Southern California) Information Science Institute, is one of the typical examples, using two IMPs in an ARPANET to support about half-a-dozen PDP-10's, as well as several PDP-11's. The net is used to support terminal access and file transfer among the hosts, and can also be used to down-line load the smaller PDP-11's. One of the PDP-11's is attached to a graphics printer, and runs as a server accessible to the net [6].

b) The second variation on store-and-forward processing does not require the separate IMPs. Instead the packet switching function is performed directly by the host. Without an independent switch, it is necessary for the host itself to be functioning in order to forward packets through the net.

This second approach eliminates the need to acquire different hardware to perform the switching function, but it will require that network software run in the hosts which make up the network, thus, consuming resources in those machines. Generally, one would configure such networks as distributed computer systems in more restricted topologies, such as ring, bus, or a star. This approach has been chosen in the design of the Priority Net. DECNET is the most widely used network that has been implemented in this approach [7].

2.3.2 Star network

Star shaped networks, a collection of point-to-point lines housed in on a single resource, are one of the simple topologies. A star network eliminates the need for each

network node to make routing decision by localizing all message routing in one central node. The star is an obvious topology to support a number of terminals communicating with a time sharing system, in such a situation the central node might be the time-sharing machine itself, moreover, the communication channels are not shared and require only a simple line control discipline. As a star system grows, individual star can be interconnected to form a hierarchically connected set of resources.

Star networks have emerged in three different forms. a) Some star networks are modelled on terminal systems, providing communication between a set of hosts and a single group of shared peripherals or other centralized resources. b) For providing more general inter-machine communication, the center of the star may serve primarily as a switch directing traffic among the various hosts, but not providing centralized services itself. c) Some star configurations implement circuit switching, to provide high capacity dedicated links among hosts.

Since all the network routing functions are performed by the central node, it must have sufficient capacity to cope with all simultaneous conversations. Hence, the central node may be a fairly large computer. The cost and difficulty of making the central node sufficiently reliable may more than offset any benefit derived from the simplicity of the other nodes. The Octopus Network is one of the typical example in this approach [8]. Another example of this approach is AT&T's Transaction Network Service (TNS) which can service user terminals with a set of concentrators and a message switch.

2.3.3 Ring and Loop topologies

The ring and loop topologies attempt to eliminate the central node in the network, without sacrificing the simplicity of the other nodes. While the elimination of the central node does imply a certain complexity at the other nodes of the network, a decentralized network can be constructed with a surprisingly flexible arrangement of nodes. In the circular topology (ring and loop), a message is passed from node to node along unidirectional links. There are no routing decisions to be made in this topology ; the sending node simply transmits its message to the next node in the ring, and the message passes around the ring, one node at a time, until it reaches the node for which it is intened. The only routing requirement placed on each node is

that it is able to recognize, from the address in the message, those messages intended for it.

All rings and loops make use of some form of active repeater or ring interface that receives the signal and regenerates it for the next host. Reliability of these components then becomes an important aspect of overall system reliability. If a ring interface is powered from its host, for example, a local power failure there will bring down the whole net. Alternatively, if one interface fails in such a way that it is corrupting many of the passing bits, that will also affect all of the hosts. Various schemes have been proposed to protect the integrity of the ring and loop : a relay which will switch the interface out of the system if the host fails powering the interfaces from the line, alternate paths to allow reconfiguration and other approaches.

The Cambridge ring designers, J.H. Saltzer and D.D. Clark [9], have outlined three difficult ring engineering problems and these are summarized here:

a) Reliability of the repeated string. As mentioned above, pinpointing a faulty repeater would require proper inspection of each repeater around the ring. By-pass relays can change the configuration into a star-shaped ring which creates a centralized location for maintenance and reconfiguration.

b) Distributed initialization and recovery. For distributed control discipline ring networks, an algorithm is required in order that all active repeaters can execute their initialization for recovery instead of interfering with one another. By jamming and releasing a virtual token, the station which executes the network reinitialization can be identified.

c) Closed-loop coordination. A common clock rate is essential for all repeaters and this requires an integral number of bit times of delay when going round a closed ring. This requirement can be achieved in at least three different ways. The most sophisticated way is to have a phase-locked-loop (PLL) in each repeater tracking its preceding neighbor.

The most important aspect of a circular design is the control procedure used to allocate access. The control procedure has slowly evolved into two general approaches: distributed and centralized control:

- A *ring* network usually incorporates some form of distributed control discipline,

eliminating the need for a special machine to serve as a controller.

- A *loop* network usually incorporates some form of centralized control at a special node, which acts as a loop controller to parcel out system resources. Thus, one has an image of a loop which starts from one particular point and returns.

In fact, the choice of one control structure or another often reflects the anticipated pattern of use. For example, if one wants to connect a large number of hosts with equal logical stature, or support a rich pattern of connectivity, a general ring structure may be appropriate, especially if it can be run without any central control. If, however, the circular structure is meant to connect a group of terminals to a single host or to a shared cluster controller, it may be perfectly reasonable to provide a loop controller for running the system.

Many researchers have designed and implemented ring and loop nets (e.g., Clark et al., 1978; Fraser, 1975; Liu, 1978; Needham, 1979; Pierce, 1972) [1]. From those examples have emerged several major alternatives for controlling a circular structure.

-Traditional polling. *Roll call polling* usually involves a designated loop controller which explicitly polls each node on the loop, giving it permission to transmit to the controller [10]. *Hub polling* is another technique in which the loop controller initiates a scan of the loop by giving control to the first node; when done, that node passes along control to the next node in the loop until the final node hands control back to the "hub".

-Token passing. In this type of ring a special bit pattern, called the token, circulates around the ring whenever all stations are idle. In order to transmit a packet from a station, it is necessary to first take hold of the token and then remove it from the ring before transmitting. Such rings often require special procedures to first generate the control token, and need recovery procedures should the token get lost or destroyed. Token passing does allow each station to send variable length blocks, only using the channel for as long as actually needed [1] .

-Contention Rings. The contention ring contains nothing at all when there is no traffic.

Basically, if a station has a signal to send, it must make sure that there is no signal passing through its interface before starting transmission. At the end of its packet, it releases a token onto the ring, just as the token ring does [1].

-Slotted Rings. The ring itself is slotted into a number of fixed-size packets. Every first bit in a packet slot is either full or empty. If a station wants to transmit, it needs to get hold of an empty slot, addresses it as full, and enters its data in the slot. Thus, while control of access to the loop is distributed among the nodes, some central control may be needed to generate and maintain the empty slots, or to provide sufficient buffering for the slots [1].

-Buffer/Register Insertion Rings. The Register insertion ring, developed by Liu (1978), is a more sophisticated version of the slotted ring. Buffer insertion, a hybrid of slotted and token rings, was developed by Hafner [1].

For a general purpose local network, the distributed approaches are usually most attractive. The Cambridge ring is the typical example of the rings using "empty slot" techniques and now is running at the Cambridge University, England. This ring runs at 10 Mbps and uses rather small packets containing only two bytes of data. The Cambridge design does have a distributed procedure for controlling access to the ring, but is dependent upon a specialized "monitor station". The monitor station is used to control the number of slots circulating around the ring, typically 2 or 3: this unit is needed to provide clocking, to initially generate the empty slots and to ensure that there is sufficient buffering to hold the circulating slots. Any packet which passes the monitor twice is presumed to be circulating, and is marked empty. Furthermore, reliability considerations led the designers to power individual ring repeaters from the ring itself, rather than depending upon their hosts for power. Thus, special connections to the ring are needed to inject power for use by the ring interfaces.

The Cambridge Ring is the most successful empty slot ring now running and supports a wide range of hosts: the Cambridge CAP, two PDP 11's, a PDP-7 and several other machines [10] [11].

2.3.4 Radio-based approaches

All of the foregoing architectures for local networks have used point-to-point physical media, configured in different topologies with various control strategies. These same approaches could be implemented using point-to-point radio links which can also provide an opportunity for broadcast transmission. The use of radio potentially offers several important advantages: longer distance, substantial bandwidth, easy reconfiguration, mobile operation and simpler installation in harsh terrains.

Again, the radio channel itself becomes a shared resource used by many different hosts, and therefore some form of control procedures to allocate that resource must be provided. A straightforward approach is to implement some sort of static allocation such as frequency division multiplexing (FDM) or time division multiplexing (TDM). Both of these take the existing bandwidth and subdivide it into some number of subchannels which can then be allocated to individual transmitters. Another centralized approach might use some form of explicit polling to communicate from one point to all other stations; this would then be a system incorporating a broadcast medium, full physical connectivity and a centralized control discipline to yield a star shaped logical connectivity. However, none of these control procedures are particularly attractive for use with bursty computer traffic.

The ALOHA system at the University of Hawaii achieved the first realization of using a set of distributed *random access* transmitting procedures for packet broadcasting in a shared channel [1]. When a terminal has a packet ready to send, it just transmits the packet and hopes no collision occurs. If a collision takes place, the terminal will not be able to receive an acknowledgement back. Therefore, the sender just waits a random amount of time and sends the packet again. This technique is called *pure ALOHA* and a maximum channel utilization of about 18.4% has been reported.

Roberts [1] proposed a method to double the capacity of an ALOHA system in 1972. By dividing time into discrete slots with each slot corresponding to fixed length packets, a terminal is not allowed to transmit until the arrival of next slot , so that the period of vulnerability is reduced to only one packet time. This technique is known as *slotted ALOHA* and a maximum channel utilization of about 37% has been confirmed by analytical examination. The tradeoff for this technique is to have some way of synchronizing various

transmitters.

Most of the radio networks described here are not really local networks, since they are often designed to span as much as a hundred miles, often using rather expensive equipement. Yet the radio work is important for two reasons. First many of the ideas proposed here have proven to be very useful in the development of other local network technologies. Secondly, the declining size and cost of both radio units and digital components hold out the promise of much more widely available radio systems that one might consider developing for use on a local scale, within a campus area or city. The new Radio Network which was installed in the Ottawa Police Headquarters recently is a typical example of this breakthrough. With this network all the police units can have access to a data bank in a very short time from any mobile location.

The availability of radio frequency spectrum is another issue which may dominate future developments of radio networks both nationally and internationally. The land mobile radio frequencies are already badly oversubscribed for voice traffic and there have been proposals for reallocating frequency spectrum specifically for local radio distribution of digital data. A similar breakthrough is the cellular radio telephone system which physically divided a oversubscribed city into different cells. Each cell is allocated its own radio frequency and every mobile telephone will be automatically switched into different frequencies in different cells. But the long term future of this work will be very dependent upon spectrum management.

2.3.5 Multiaccess bus structures

For a general purpose local network, full logical connectivity among all hosts is the most attractive issue. The use of distributed control procedures helps to eliminate any dependence upon the proper functioning of a single controller. For the bus structured networks, there are no routing decisions required by any of the nodes. A message flows away from the originating node in all directions to the ends of the bus. The destination node reads the message as it passes by. Again, a node must be able to recognize messages intended for it.

In addition to the experimental Priority Net and Ethernet, there have been about a dozen other proposals for networks designed along these lines. The experimental Priority Net network was developed in the Dept. of Electrical Engineering in University of Alberta and it is the first collision-free multiple access (CFMA) system using a single coaxial cable to be

actually implemented. Chapter III reviews these existing bus networks and also describes other techniques for using a shared multiaccess bus.

CHAPTER III

ANALYSIS AND EXAMPLES OF MULTIACCESS BUS STRUCTURES

3.1 ANALYSIS OF MULTIACCESS BUS STRUCTURES

Traditional multidrop lines have used a twisted pair or coaxial cable as a broadcast channel, typically combined with a centralized control discipline, such as polling, to lay a star shaped logical connectivity on top of the full physical connectivity provided by the broadcast channel. CATV (Cable Television) systems also provide a wire-based broadcast channel, frequently managed by a controller at the CATV *head end* .

All the nodes in a bus structure, unlike nodes in a ring, do not have to repeat and forward messages intended for other nodes. As a result, there is no delay and overhead associated with retransmitting messages at each intervening node and the nodes are relieved of network control responsibility. Because of the passive role nodes play in transmission on the bus, network operation will continue in the event of node failures. This makes distributed bus networks inherently resistant to single-point failures. This advantage has led to the development of a whole family of multiaccess bus structures with distributed control, of which the pioneering example is the Ethernet.

Starting from the idea implemented in the ALOHA networks, the enhanced Ethernet random access strategy includes several additional features:

- The combination of carrier sense multiple access and collision detection, which is generally not feasible with radio, is feasible with other broadcast channels.
- A collision consensus enforcement procedure, after a collision, ensures that all parties to the collision have properly detected this event.
- To assure stability, a binary exponential backoff provides a very reasonable retransmission algorithm. That is, the waiting intervals of retransmission in a station are in exponential form, e.g., 2, 4, 8 units and so on.

General Ethernets, or other commercial networks, can be used on various media which provide broadcast channels (twisted pair, fiber optics, etc.), but the most important

applications have made use of coaxial cable. There is also no central controller in Ethernet, no store-and-forward processing, and no dependence upon software running in other machines. However, owing to the potential difficulty in locating faults on a bus, network management capabilities or test equipment must allow fault detection and isolation to facilitate repair and maintenance.

3.2 EXAMPLES OF MULTIACCESS BUS STRUCTURES

3.2.1 The Ethernet

The original Ethernet-style approach uses a broadcast channel and an access procedure that includes carrier sense multiple access, collision detection, collision consensus enforcement and a dynamic backoff algorithm. Implementation of this basic strategy involves several design decisions, including selection of the particular type of broadcast media, the data rate, coding technique, addressing, packet formats, and others. In addition, after the basic network characteristics have been determined, there are still many additional design decisions associated with the construction of any particular interface: allocation of functions among hardware/microcode/software, address recognition, proper signal isolation, a watchdog timer to prevent runaway transmitters, implementing of the backoff algorithm and others.

The Ethernet approach was first implemented in the experimental Ethernet system at the Xerox Palo Alto Research Centre [12] [13] [14] [15] [16] [17]. A typical Ethernet uses a coaxial cable as the shared transmission medium and CATV connector hardware as the MAU (medium access unit) to provide internetworking services up to a maximum of 256 stations. Control of Ethernet is completely distributed among stations. Transmissions initiated by a station defer to any which may already be in progress. Once started, if interference with other packets is detected, a transmission is aborted and rescheduled by its source station. After a certain period of interference-free transmission, a packet is heard by all stations and will not be interferred till the end of transmission. Ethernet controllers in colliding stations each generates random retransmission intervals to avoid repeated collisions. The mean of a packet's retransmission intervals is adjusted as a function of collision history to keep channel utilization near the optimum with changing network load.

The only shared component in an Ethernet is the coaxial cable. There are no repeaters, no buffering in the interfaces, and no power on the line. Furthermore, there is no central controller, no source of clocking nor synchronization, and no monitoring station needed.

3.2.2 Ethernet-like systems

The Ethernet design now serves as the canonical example of such cable-based multiaccess bus networks, but there have been many other variations on this theme. We will try to highlight some of the distinguishing characteristics and different design decisions which have been proposed or implemented.

NET/ONE (Ungermann-Bass Inc). Net/One is a local communication network which was designed to make use of wide range of communication media. In its first embodiment a linear bus technology similar to the experimental Ethernet was used [18] . Current implementations consist of a single baseband, coaxial cable and an arbitrary number (2-100) of network interface units (NIUs) placed at arbitrary locations along the cable or cable plant. The NIUs are packet switching computers which employ special hardware and software to provide user devices with communication services. The NIUs transmit information on the shared coaxial cable at 5 Mbit/s or at 10 Mbit/s depending on which of two current data rate options is selected. Individual Net/One segment may be joined in an internetworking arrangement by the use of bridge processors. All Net/One protocols employ internet headers to allow for whatever future extensions prove necessary.

The basic means by which the NIUs gain access to the shared baseband coaxial cable is through the use of a (CSMA/CD) technique. In this scheme NIUs listen before transmitting to ensure the channel is free, and listen during their own transmissions to ensure no other NIUs transmit at once, or detecting a collision the colliding stations reschedule their transmissions for another attempt in the future. In conclusion, the baseband version of Net/One uses CSMA/CD.

NBSNET. At the National Bureau of Standards an Ethernet-like system is being proposed as a mean to support host connections as well as a large number of "dumb" terminals, all using

regular RS-232 interfaces [19]. To accomplish this, up to 8 low speed ports connect to a special controller (the Terminal Interface Equipment, or TIE); this controller then interfaces to the 1 Mbps multiaccess bus. The TIE includes packet buffers and a "network board", as well as individual "user boards" for each terminal.

The major protocol technique adopted from Ethernet is to detect the cable before transmitting to ensure the channel is free. When nodes detect collisions, each party to the collision can immediately truncate the packet being transmitted and self-impose a random waiting period before attempting to regain control of the cable. The waiting periods are taken from a unique random table in each user's node. Since collisions should occur near the start of a packet, truncation avoids tying up the network with complete transmissions of already damaged packets.

<u>Z-NET (Zilog)</u> The Zilog LSl component for communications (SIO) chip is also used at the heart of Z-NET, an Ethernet style system now being developed at Zilog [20]. In this network, a SIO is attached to the bus in a Z80 development system, moving packets directly into main memory. The SIO chip generates SDLC-style frames (Synchronous Data Link Control), sends them to the transceiver where they emerge on the cable. The cable can be up to 2 Km in length, interconnect up to 255 independent microcomputers and operate at 800 Kilobits per second. The "Ethernet" like network architecture was choosen for its distributed control stability and ease of expandability. Higher performance could have been achieved via the use of 16-bit microprocessors and discrete logic, however, the cost would have been prohibitive for many applications.

<u>ACKNOWLEDGING ETHERNET (Keio University).</u> This is a proposal to modify slightly the carrier sense procedure in order to enforce a silent period at the end of every data packet, in which the recipient could immediately launch an acknowledgement back to the source. Ethernet, however, provides no built-in message acknowledgement scheme such as provided by the ring networks. Rather, a message packet is used to notify the transmitting host that a message has been acknowledged. This will decrease the transmission efficiency and increase the loading on the host computer. In Acknowledging Ethernet, any transmitter which is ready to send is required to wait for this silent period to elapse before it can transmit, since it may have

been awakened in the middle of a period reserved for the response. This would have to be a low level acknowledgement from the I/O controller, however, and not a response from a higher level protocol module. The analytical work in support of this proposal assumes a zero turnaround time between arrival of a data packet and generation of the acknowledgement [21].

Above 4 different design efforts clearly suggest that the notion of a shared multiaccess bus with distributed control has some appeal. Some of the designs exist only as proposals; of those which have been implemented, none have reported any systematic performance measurements. There are still many other Ethernet-like systems which have been implemented or proposed, such as

- ENET and CNET (Queen Mary College, London), implemented.
- CYBERNET/LNA (Ford Motor Co.), implemented.
- FORDNET (Ford Aerospace), implemented.
- BATNET (Battelle-Northwest, Washington), implemented.
- CHAOSNET (MIT AI Lab.), implemented.
- NAVCOSSECT (U.S. Navy), implemented.
- PERQ (Three Rivers Computer Corporation), proposed.
- Priority Ethernet (University of Tokyo), proposed.

3.2.3 Using CATV for sending data

A regular CATV installation reflects the original intention to support TV distribution, and differs in several important ways from the Ethernet use of this equipment [22].

- CATV has much greater bandwidth requirement, allocating 6MHz per TV channel.
- Instead of baseband signalling, it uses a modulated carrier, from about 50 MHz to 270 MHz.
- To properly carry these signals over resonable distances requires the use of active line repeaters, amplifying and regenerating the analog transmission.

- Power is often supplied to these repeaters through the line itself.
- The system usually has the topology of a uni-directional tree, with a *one-way* flow of signals out from a single source at the *head* end.

The last characteristic is a perfectly reasonable approach to the distribution of TV, but makes it difficult to support general data traffic. There are two techniques for providing two-way transmission on a CATV network. One method is to have the regular forward channel (50 MHz to 270 MHz) supplemented with a reverse channel spanning 5 MHz to 30 MHz. With this frequency division it becomes possible to build two-way amplifiers which can simultaneously amplify in both directions. Alternatively, two-way communications can be provided by installing a dual-cable system, using one cable for outbound signals and another for inbound.

In either case, the CATV system really provides two channels, a multiple access inbound link and a broadcast channel coming back out. To send information between two different points on the system, the head end will need to do the appropriate frequency shift and retransmit. Thus, a CATV bus system can serve as a broadcast communication channel in a local network; as a shared resource, there is now a need to provide some means to allocate use of that channel.

3.2.4 CATV-based local networks

During the last decade one of the strongest and most consistent advocates of the use of CATV for carrying data has been a group at the Mitre Corporation. Their work has explored the integration of this data service with regular TV, and several successive designs have incorporated different control strategies. Early implementations of MITRE's cable-bus network (MITRIX) utilized the type of time division multiple access (TDMA) scheme which was originated from the access mechanism of "slotted ALOHA". Cablenet at MITRE/Washington utilized the Carrier Sense Multiple Access (CSMA) with Listen-While-Talk (LWT) technique.

CABLENET (CSMA/LWT). This CABLENET design uses frequency division multiplexing to

allocate a portion of the CATV bandwidth for use as a shared multiaccess channel. With a dual-cable configuration, however, the carrier sense and collision detection operations do not take place at just one point on one cable. Instead, a device first listens for signals on the outgoing cable and transmits on the incoming cable when it is free. The device cannot detect any collisions directly from the transmitter, but monitors possible collisions on the outbound channel, when its' own signal appears. Thus, the collision detection must be done by comparing the current input from the cable and the output sent some period before. While the Ethernet has a maximum collision window equal to twice the propagation time down the length of the cable, this dual-cable approach increases the maximum window to 4 times the propagation time from the furthest device at one end to the distant head end.

Furthermore, the system detects collisions only on the first 16 bits of a packet, and does not use collision detection to monitor the packet during transmission. Retransmission periods were chosen from a fixed interval, and no dynamic control of retransmission intervals was provided. Again, devices connected to the system through a Bus Interface Unit (BIU) which included packet buffers and a microprocessor. Prototypes were developed at several speeds, e.g. 307.2 Kbps or 1.2 Mbps; the only installation site is at Mitre/ Washington [23].

As CATV systems continue to grow, and as their designers seek out new markets and service offerings, we can probably expect an expansion in the use of CATV for carrying data. Other related systems were also supplied by Mitre, such as

- PROMIS (Promis Medical Information System).
- Mitrix II (Central Intelligent Agents, U.S.A.).

3.2.5 Fibernet

Local area networks which communicate over electrical paths typically operate at bandwidth•length (Bw•L) products up to a few MHz.Km. With the introduction of optical fibers as a transmission medium, local area networks can offer higher bandwidth with a medium that has less physical weight than twisted pair or coaxial lines. Unfortunately, the

current technology does not provide a simple way to construct a passive fiber optic tap, which would be needed to support an Ethernet-style cable system. The Ethernet approach could be employed if fiber optics are used to connect active repeaters at each host; but that then introduces a number of active elements into the shared portion of the system [24].

Fibernet, which was installed at Xerox Palo Alto Research Center [25], is a star-configured fiber optic network. Fibernet employs fiber optics to form a broadcast medium by running individual fibers from each host to a central point and rebroadcasting the signal from there. The central point of this star is a 19-port transmissive star coupler which function as a mixer. Every station will be connected to both ends of the transmissive star coupler by a fiber with one end serves as transmission and the other as reception. Fibernet uses a 19-port transmissive star, GaAlAs injection lasers and avalanche photodiodes, and incoperates bi-phase (Machester) encoding. Access to this Fibernet channel can be controlled with a distributed procedure similar to Ethernet.

In an experimental Fibernet configuration, a 1/2 Km of fiber running through a 19-port transmissive star coupler at 150 Mbps of pseudo random data, no error has been detected in a test sequence of 2×10^{11} pulses. With the length increased to 1.1 Km and the data rate reduced to 100 Mbps, the channel produced a bit error rate (BER) of 1.1×10^{-9}. The Fibernet operates with a Bw•L product of around 100 MHz.Km at a data rate of 150 Mbps.

3.2.6 Hyperchannel

The Hyperchannel product family of Network Systems Corporation (NSC) represents the first commercially available cable-based local network. In general, this system is targeted for use within large computer centers, as a means to tie together very high performance machines and their peripherals. The early efforts were aimed at CDC 6600's and 7600's. The design uses a single coaxial cable, with a data rate of 50 Mbps. It was first prototyped several years after the Ethernet, and the approach differs in several important ways [26].

The Hyperchannel is based upon the use of a specialized network adapter at each host. The device allows the network itself to look like the appropiate end of a channel interface to either a large mainframe or peripheral. The adapter includes a microprocessor and packet buffers; data packets are copied back and forth between the host and the adapter at a rate

which may be different than the 50 Mbps cable rate. This adapter is also responsible for implementing a specialized adapter-to-adapter protocol, which includes provisions for returning a low level acknowledgement for every regular packet sent to the destination adapter.

The low level channel access protocol uses a prioritized variation of carrier sense multiple access (CSMA), but does not provide any form of collision detection. If the channel has been idle for a lengthy period of time, two hosts may both transmit and collide, but the packets must both run to completion, and the error will be detected by lack of a return acknowledgement. Instead of a dynamic backoff, a timer-based mechanism is used to resolve collision and allocate the channel, triggered by every packet at the following steps.

* Immediately after a packet passed there is a fixed delay in which the destination adapter may generate the appropriate acknowledgement, and during which no other host will transmit. This is similar to the Acknowledging Ethernet proposal.
* The time after that is slotted into a series of short intervals in which specific hosts are assigned successive slots, in priority order: the highest priority one goes in the first slot, the second priority host gets to go next if the channel is still free; and so on through the hosts.
* Appropriate timers are maintained in each adapter, and resynchronized at the tail end of each packet. If after a packet all of the priority slots pass with no new transmissions, then the channel is again free, or in a contention mode.

This approach can provide for priority use of the channel by particular hosts. The price paid for this is that lower priority hosts must always wait for access to the channel, even if no higher priority hosts are transmitting.

3.2.7 Other bus systems

Our discussion of bus systems has primarily focused upon the board family of Ethernet-style systems, and varying schemes with distributed control. Several other specific proposals or implementations for bus-based local networks have been put forward as well.

* Decentralized switching for telephony - An architecture similar to that used for dual-cable CATV has been proposed as a means to carry integrated data and telephone signal [27]. In this scheme, two parallel branching bus structures are connected to each telephone or host, one used to transmit and one used to receive.

* Broadcast infrared channels - Another alternative communication medium is the use of diffused infrared radiation within a single room [28].

* Microprocessor bus system - The Honeywell Experimental Distributed Processor (HXDP) was meant to provide inter-processor communication over distance of about 1 Km. A passive serial bus was used, running at 1.25 Mbps and it was controlled with a distinctive form of roll call polling known as Vector-Driven Proportional Access (VDPA) [29].

3.3 OTHER COLLISION-FREE NETWORKS

Collision means that two or more stations transmit simultaneously such that their electrical signals are superimposed and collided. Some protocols allow collision in the contention window but some do not. The latter one is referred as *collision-free* protocol. In this section, a number of collision-free networks will be discussed.

3.3.1 Collision-free Local Bus Network from University of Toronto

Hamacher and Shedler [30] recently proposed a distributed access control scheme to provide collision-free communication networking among hosts. The proposed scheme has made the most use of its bus bandwidth, only a small fraction of time exists when the bus is idle while at least one host is ready for transmission. On the other hand, it is possible for two ports that always have packets available for transmission to stop other ports from accessing the bus indefinitely. This scheme leads to an unrealistic loading situation.

As shown in Fig. 3.1, let N be the maximum number of hosts, and refer them as port 1, 2, ...N. For each port K, ports 1, 2,......K-1 are said to be on the left of port K, and ports K+1,....., N are said to be on the right of port K. Every port observes the bus to be busy when its receiver detects signals on the bus, otherwise, the bus is said to be idle.

Let T be the propagation time delay between the two most widely separated ports and R(K) be the propagation time delay along the control wire from port K to port N. The following steps show the access control algorithm for port K (as shown in Fig. 3.1).

* Set Z(K) to '1'
* Wait for the propagation time delay R(K)+T
* Monitor and wait until the bus is detected (by X(K) of port K) to be idle AND Y(K)='0'; then start transmission of the packet, simultaneously resetting Z(K)='0'

By executing this control scheme in each port interface logic, collision free communication among ports can be achieved. This control scheme does not require assumptions regarding the mechanism for the arrival of packets at the individual port for transmission. The waiting interval at the worst case will be R(1)+T in all ports provided they all execute exactly the same algorithm.

The potential blocking property does exist in this collision-free control scheme, therefore, no guaranteed time for transmission at all ports is provided. Let us have a look for a simple example with a three port network. We must assume that the packet time must be much greater than R(1) and the arrival of packets in a port for transmission must be continously. If port 1 starts to transmit a packet and all the other ports set their Z(K) to '1'. It is obvious that port 3 at the rightmost end never get a chance to transmit because it never observes the bus to be idle and Y(3) to be '0' simultaneously. However, it is guaranteed that port 1 and 2 will exhibit no blocking for their transmission. For this reason, this control scheme has practical limitations.

3.3.2 Collision-free subnetworking of Welnet in University of Waterloo

Welnet use FSK (Frequency Shift Keying) signalling method with modems attached to each node. The subnetworking of Welnet is a ring topology with a centralized controller. The controller sends a high signal through the ring in anticlockwise direction and each port (station) has the same configuration as mentioned in Fig. 3.1b. With Z(K) in all ports set to '0', this high enable signal (actually it is a low to high transition) will return back to the controller after

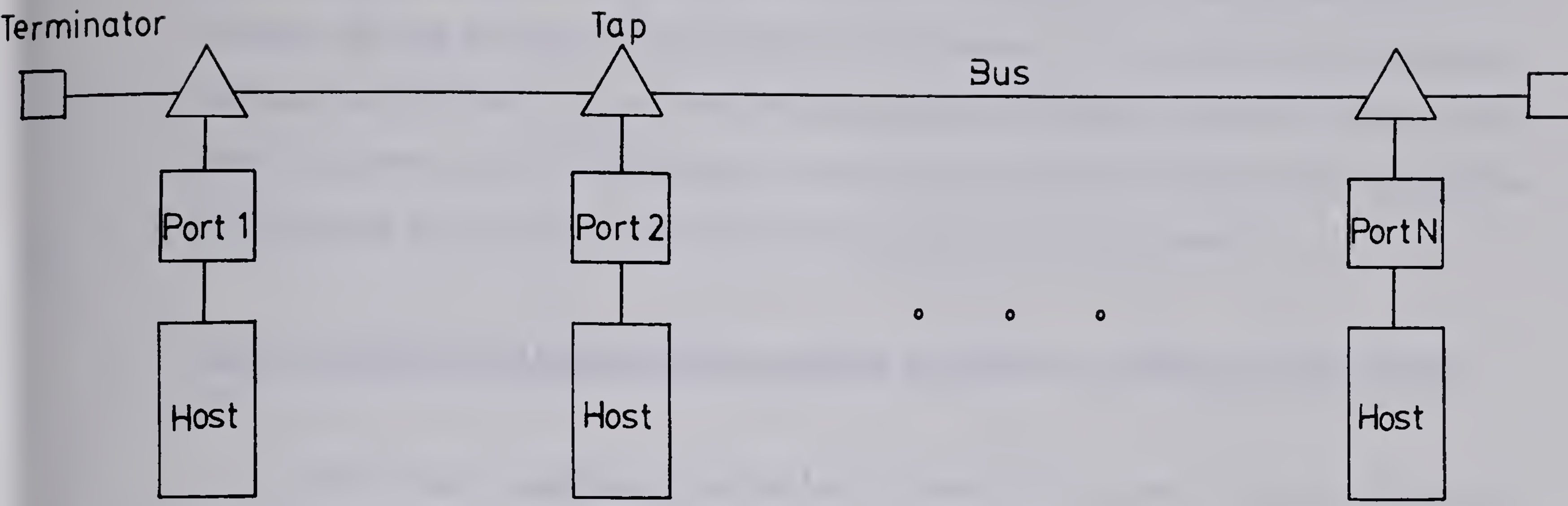
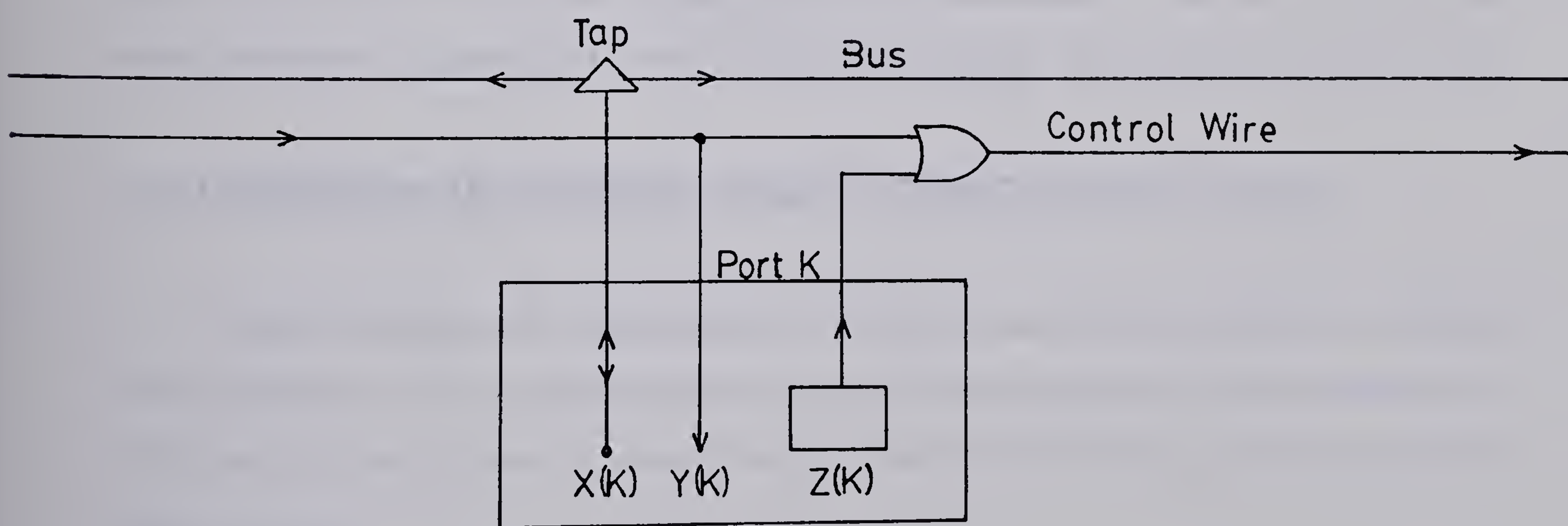


Figure 3.1a Communication bus network



Note: X(K) = Send flip-flop at Port K
Y(K) = OR-signal entering Port K
Z(K) = Bus access point for Port K

Figure 3.1b Port interface logic (Adapted from [30])

a round trip propagation delay. If any one wants to transmit, one just simply sets Z(K) to '1' to prevent the rest of stations from picking up this transition. After finishing its transmission, this transition will pass to the next station in anticlockwise direction, just like the token passing scheme. However, proper functioning of the centralized controller is essential for the operation of the network and a single point failure here brings down the whole system.

3.3.3 An Assigned-Slot Listen-Before-Transmission Protocol for a Multiaccess Data Channel

This protocol originated from Bit-Map Protocol [1] has been revised by Hansen and Schwartz in 1979 [31]. For N stations from 1 to N, there are exactly N slots in each contention window. Station 1 transmits a 1 bit in the first slot if it has a packet to send. This first slot is reserved for station 1 and no other station is allowed to access it. Station 2 has the chance to transmit a 1 during the second slot if it has a packet to send. After monitoring all N slots, each station will know which stations are ready to transmit. They start their transmission in numerical order in that instant as shown in Fig. 3.2a.

In Hansen and Schwartz's version [31], each station begins its transmission immediately as far as it inserts a 1 bit into its slot. Bit scanning in the contention window is started with the station following the one just transmitted. Instead of starting the bit scan in the contention window with station 1 each time, rotating priority can be executed. Every station has its own control whether to transmit right away or let its bit slot go idle. This is illustrated in Fig. 3.2b.

3.4 A COMPARISON OF DIFFERENT LOCAL NETWORK ARCHITECTURES

Some advantages and disadvantages of each family can be distinguished from different LAN architectures. Clearly each approach may have some strengths and some weaknesses, and all of them will be evaluated in terms of host-to-host traffic, allowing direct communication among all hosts.

* Partially connected systems do provide the potential for alternative paths between hosts, but also yield increased complexity. The packet switching programs, procedures for dynamic routing, and techniques for maintaining and updating the routing tables must be

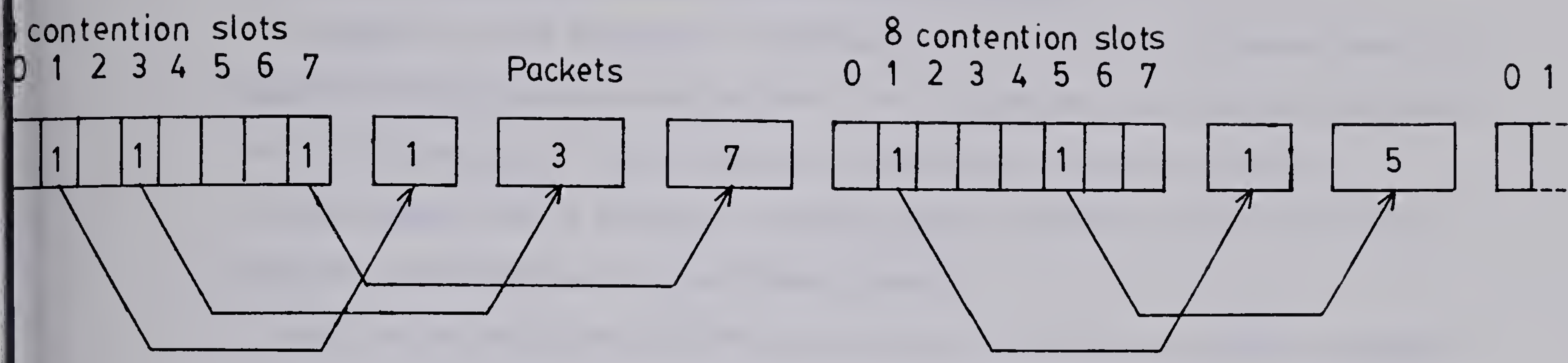


Figure 3.2a Bit-map protocol

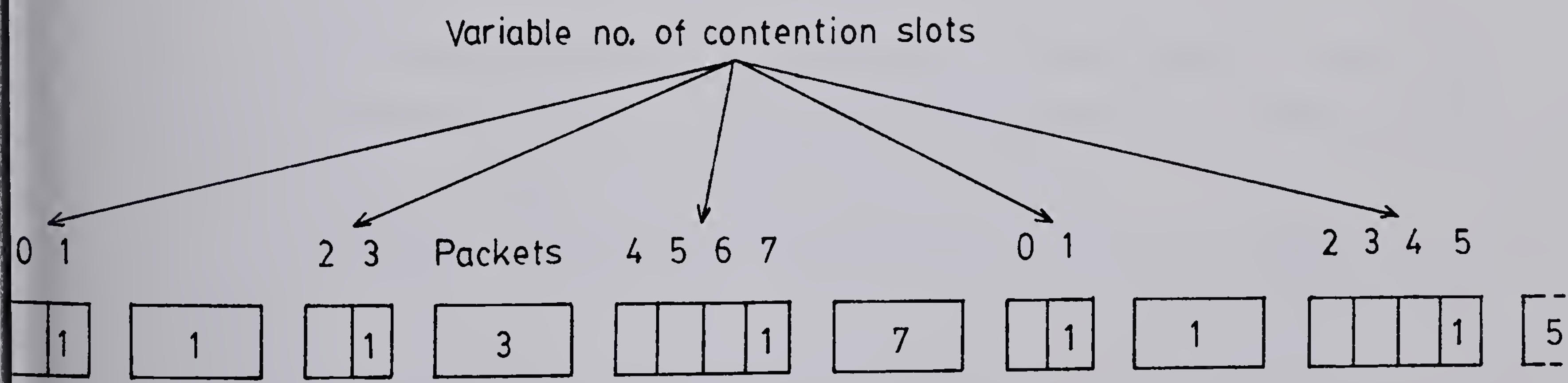


Figure 3.2b Assigned-slot protocol (Adapted from [31])

accomplished. The store-and-forward techniques also impose additional store-and-forward delays as packets move through the system.

* A simple star often represents a convenient architecture, but is dependent upon the behavior of the switching node at the center. Any failures there will bring down the entire net, and the switch may become a bottleneck since all traffic must pass through it.

* Loop systems with a centralized controller possess problems similar to the star -- reliability and performance at this key central location.

* Radio may become a very attractive alternative in the near future. However, frequency spectrum allocation difficulties and potential propagation problems within some structures do not make it a desirable approach for local networks.

* Similar to circular structures, a single bus is vulnerable to major failure which cuts the bus. But the bus structure with distributed control reduces to an absolute minimum the amount of shared resources, helping to improve the overall reliability. With a suitable design they can provide for smooth incremental growth, and very easy installation and reconfiguration. In addition, the broadcast channel does not introduce any store-and-forward delay, and there are no active repeaters to introduce any delay.

CHAPTER IV

DESIGN AND IMPLEMENTATION OF PRIORITY NET

4.1 INTRODUCTION

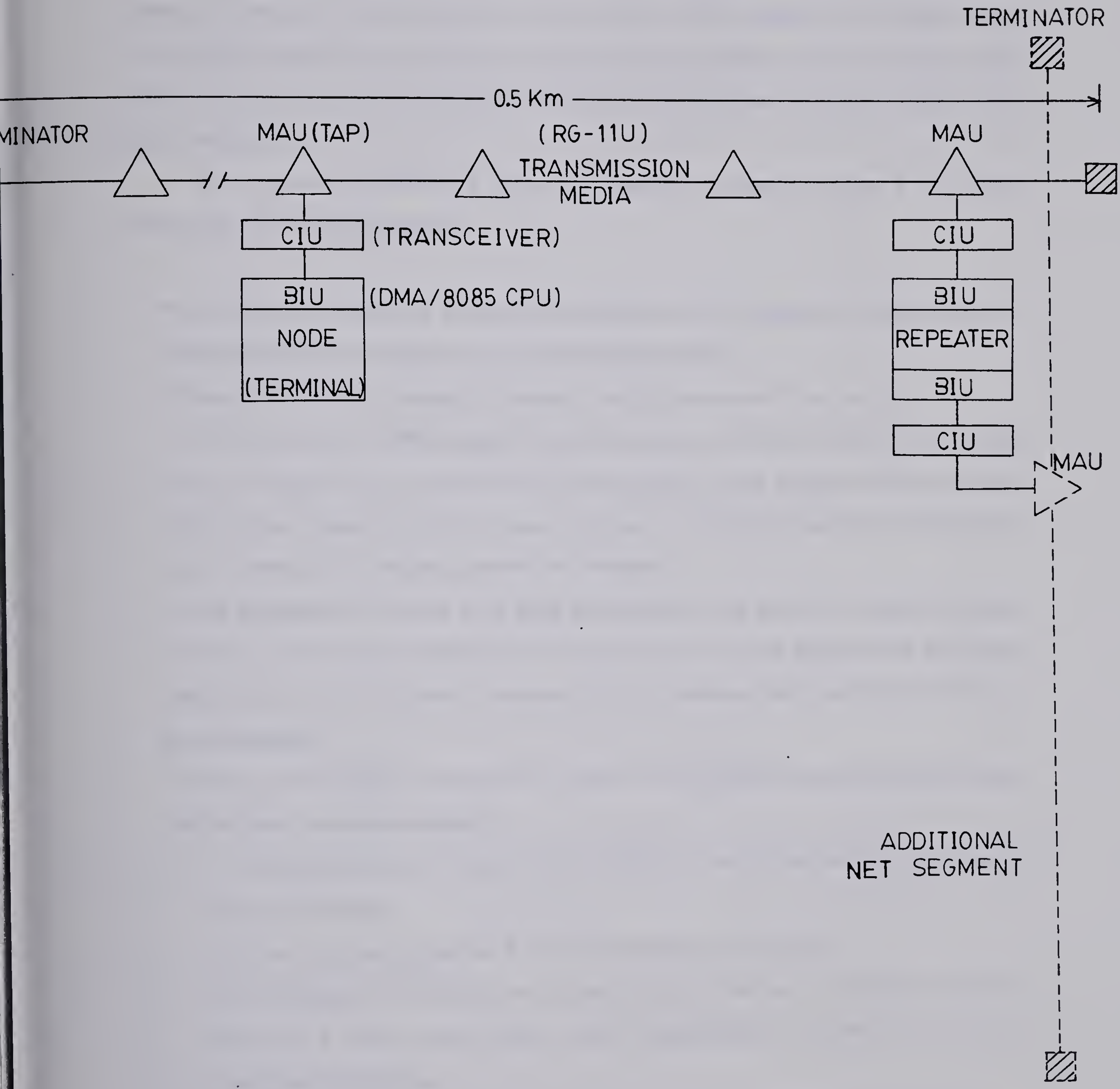
The basic principles, which will be discussed later, underlying the Priority Net can be applied to any broadcast channel including radio or fiber optics; but the experimental Priority Net was based upon the use of coaxial cable. The concept of the Priority Net was modified from the Alberta Bus that was invented by Dr. D. Zissos and implemented at the University of Alberta in 1983.

The experimental Priority Net, a CFMA bus network using simple control discipline, is able to provide a reliable, low cost and easy maintenance communication service to 4 "dumb" terminals at this stage. One segment of the Priority Net is illustrated in Fig. 4.1 which also shows how two segments can be interconnected.

4.2 DISTRIBUTED CONTROL OF PRIORITY NET AND HOW TO HANDLE COLLISIONS (BACK-OFF)

With a shared multiaccess cable, one still needs a control discipline by which stations can obtain access to the channel. To promote reliability, it is preferable to avoid any kind of centralized control, but, to use a distributed access mechanism.

The distributed CFMA access mechanism in the Priority Net was designed to provide priority access to the bus in the contention window. Collision is not allowed. Every station is assigned an unique source ID which will determine its priority. Stations with a packet to send will contend for the bus by sending their source ID in the contention window. A "1 overrides 0" scheme has been implemented so that stations with lower priority need to backoff after the contention window. The packet formats for heavily loaded and lightly loaded states are shown in Fig. 4.2a and 4.2b respectively. For a heavily loaded state, it is possible that at least one station will contend for the bus in every contention window. For a lightly loaded state, there may be no stations contending for the bus. Every packet is proceeded by an ending flag which is a unique byte of the following format [01111110], it is the synchronization byte for all



Note: Only one segment has been implemented

Figure 4.1 One segment of the Priority Net

stations. By using stripping/stuffing techniques, no other bytes in this form are permitted. To a user, a packet then begins with an 8 bits of contention window and 8 bits of destination address, followed by 8 bits of response from the receiver. If the response is "Go Ahead", then the next packet begins with 8 bits of source address and some number of 8-bit data bytes, called TEXT, followed by 16 bits of software generated cyclic redundancy checksum (CRC) and 8 bits of ending flag.

If we assume that station A wishes to transmit a message to station B, the CFMA protocol has the following sequence:

* An ending flag is detected by station A's receiver which is constantly monitoring the bus. (the ending flag is provided by the last transmitting station)
* Since station A has a message to transmit it will put its source ID on the bus.
* If A does not get a backoff signal from another station of higher priority after the eighth bit of the source ID, it then becomes the bus master, and it starts to provide the clock while the last transmitting station ceases to do so. (The system has been implemented so that '1' overrides '0' during the contention window.)
* The destination ID from A is then transmitted, with all other signed-on stations listening. Each station compares the ID with its source ID and generates the appropriate interrupt for its CPU (Central Processing Unit) if it matches their own source ID, i.e. B in this example.
* Station A then awaits a response from station B, and therefore stops providing the clock. One of three responses is expected.
    i. The destination ID - indicating that station B is available on the bus, and is free to accept the message.
    ii. Busy flag - indicating that B is in service but busy [01111111].
    iii. No response - indicating that station B is out of service. Accordingly, station A waits for a certain time before it starts retransmitting, starting with a flag to synchronize all stations.
* In the case of (i) above, station A retransmits its source ID followed by the TEXT.
* On terminating the text an ending flag is then sent out to notify all other stations that the message is completed.

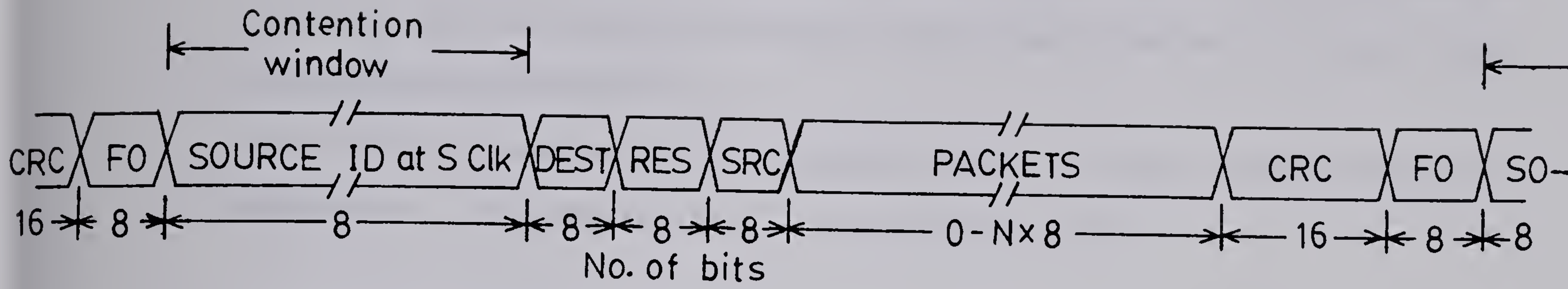
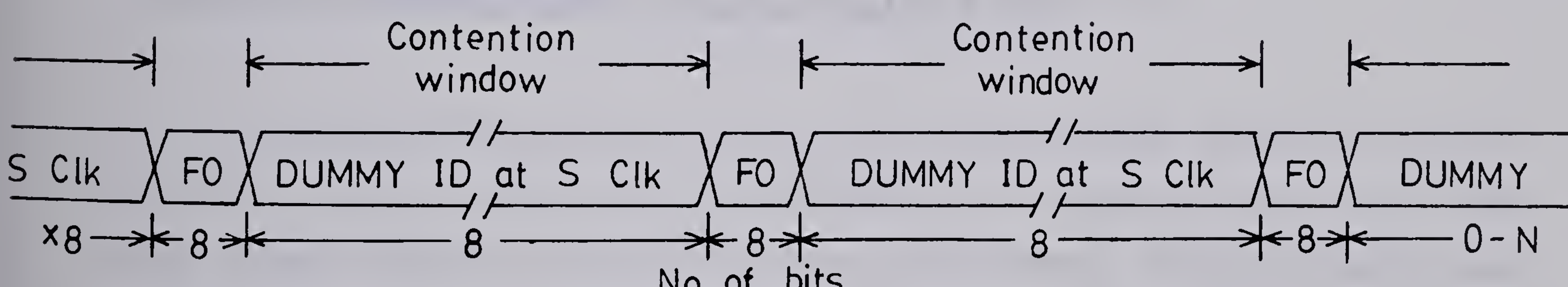


Figure 4.2a Priority Net packet layout during heavily loaded state



Note: CRC=cyclic redundancy code
DEST=destination ID
FO=01111110
DUMMY ID=00000000
S Clk = Slow clock at 31.25 Khz
Nmax.= 394 bytes
RES=response
SRC=source ID

Figure 4.2b Priority Net packet layout during lightly loaded state

* Station A then starts transmitting a dummy ID [00000000] which is the lowest priority possible. If station A receives a backoff signal during the contention window, another station will take over the bus at the end of this contention window and station A stops transmitting [as shown Fig. 4.2].

* If station A does not receive a backoff signal and it has a message ready for transmission, it then sends its source ID and proceeds as above.

If two or more stations have a message to transmit, they will transmit their source ID immediately after the ending flag and only one station, which has the highest unique source ID, can win the bus. By enforcing the contention window, we are guaranteed to have a reliable collision-free channel for hosts to communicate. This experimental Priority Net is designed to run at 1 Mbps on 0.5 Km of coaxial cable.

Since 8 bits of source ID can support 254 stations plus one broadcast address and Dummy ID, we can reduce the number of bits in this contention window as the number of stations connected to the bus is reduced. As mentioned in the work of Metcalfe [12], the average number of stations connected to a network is around 56, therefore, it is reasonable for us to transmit 6 bits of source ID instead of 8 bits to reduce the overhead. Similarly, we require only 2 bits to encode the three possible responses from the receiver station.

4.3 DESIGN CONSIDERATIONS FOR THE PRIORITY NET

As mentioned in Section 2.2, there are five major technology decisions that must be made for a local area network such as the Priority Net. In addition, there are some other minor design elements as we can see from the following. Before discussing these considerations, all the signals on the system block diagrams of the Priority Net (Fig. 4.8 and 4.9) and their significances are listed below: [all signals are high enable]

F0 = Ending flag. e.g., 01111110.

F1 = Busy flag response from receiver. e.g., 01111111.

F2/F3 = Station's own ID/Go Ahead signal from Programmable ID detector.

C = Global clock.

Di = NRZ global received data.

Do = NRZ global transmitted data.

K = Clock output from stripper.

Eta= Request to transmit signal.

Etb= Transmit enable signal.

Etx= Transmitter enable signal.

Er = Receiver enable signal.

I = Use your internal clock to transmit.

Z = Slow clock control.

P = Packet message [after "return" key pressed].

TC = Terminal count from DMA controller to indicate the end of present DMA cycle.

Etc= Enable Tc signal.

B = Backoff.

F clk = Fast clock at 1 MHz.

S clk = Slow clock at 31.25 KHz.

N = Bit to produce different RST instruction e.g., 1=RST 7 and 0=RST 6.

Note: Eta and Etb combine to produce Etx

e.g., Eta=1, Etb=1, then Etx =1 (Normal transmission)

Eta=1, Etb=0, then Etx =0 (just latch data into shift register)

4.3.1 Topology

A multipoint link topology has been choosen in the Priority Net in which a single line is shared by more than two nodes. Multipoint lines minimize the number of lines required to connect nodes and future expansion is easily carried out. As described in Saltzer's work [9], bus topologies are more easily implemented when compared to a ring technology. For these reasons, we chose a bus topology for the Priority Net.

4.3.2 Addressing

As mentioned in Section 4.2, the CFMA protocol of the Priority Net provides full logical connectivity even if the physical connectivity is less complete. Furthermore, a broadcast address is reserved to transmit public messages such that the Priority Net can also be used as a broadcast system.

4.3.3 Switching technique

Packet switching technique was developed as a solution to message exchange in computer communications. Packets can be of fixed or variable length. With this packet switching technique, the maximum packet size in the Priority Net is 394 bytes [3144 bits] but can be increased as the buffer capacity is increased.

4.3.4 Transmission medium

Generally, there are five technologies that can be considered as choices for the physical link transmission medium [32]. These are

* Twisted pair wire.
* Coaxial cable.
* Fiber optic strands.
* RF link.
* Diffused infrared radiation in a small area.

Of these, RF and diffused infrared radiation will not be considered in this study. Clearly, there are a number of factors other than cost that bear upon selection of the most appropriate choice for physical link technology in data communication application. Table 4.1 lists application areas in data communication and corresponding performance variables. Entered in Table 4.1 is an estimate of the significance of a performance variable in each of the data communication applications, a corresponding range of required link bandwidth, and link

Table 4.1 Data communication application

Performance Variables / Applications Areas	Link Data Rate/Bandwidth	Link Communication Cost	Link Protocol Complexity	Link RF Susceptibility	Link Logic Complexity	Link Reliability	Link Weight/Vol
Internal System Communications - Bus - Storage to register etc.	10	7	2	4	8	7	4
System to Peripheral Communication - Terminal to processor - Disk to processor	7	8	4	6	9	7	4
System to System via Dedicated Path - Distributed computer	8	8	7	9	9	10	8
System to System via Network - ARPA - Tymnet	6	4	10	9	2	5	3

Note: Matrix Entries: 10 - most significant (Adapted from [32])

0 - least

lengths.

Each choice of physical link technology has its own area of application. However, in some applications, like LAN design, bandwidth•length (Bw•L) product is more important than the cost factor. Table 4.2 summarizes the transmission rate versus length data for 4 lengths and 4 technologies. As planned, the Priority Net will eventually support a network at 5-10 Mbps within a distance of 1 Km. Fiber optics seems to be the best choice in terms of Bw L product but it requires expensive and active repeaters at each host. In view of this limitation, coaxial cable with its long history of usage in CATV technology provides the best currently available choice.

4.3.5 Signalling method

In the transfer of digital data, the elements of time and space are important. Imperfections in the transmission media can give a degredation in the space relationship of a data stream. Timing difficulties can lead to data misinterpretation. Also, it is necessary to separate not only individual bits of data, one from another, but blocks of data must also be identified. The information to be transmitted must be encoded or multiplexed over a serial channel in such a way that the receiving processor is able to take information from the line, including data and clock. Fig. 4.3 shows a number of coding schemes commonly used in baseband digital transmission.

If the transmission involves long strings of 1's or 0's, then clock information would not be available. This major problem exists in the encoding schemes of digital signal format such as Return-To-Zero (RZ), Alternate Digit Inversion (ADI) and Bipolar with RZ pulses. Manchester, Pulse Width Modulation (PWM) and Pulse Amplitude Modulation (PAM) encoding guarantee that there will be a transition in every bit cell, thus allowing automatic clock recovery from the signal. PAM encoding requires non-logic level amplitudes, faster rise time (which implies a larger bandwidth channel), while Manchester encoding requires complex sampling circuits. PWM encoding has been choosen in our design as it appears to be the simplest of these three possibilities [33] [34] [35].

Table 4.2 Recommended data rate per second per cable

Cable Type \ Cable Length	<100 m	250 m	500 m	1000 m
Twisted Pair	20	3	0·8	0·5
Shielded Pair	20	20	8	3
RG-59 Coax	20	15	10	4
Fiber Optics	> 20	> 20	> 20	> 20

Note : Data = Mbps (Adapted from [32])
m = meters

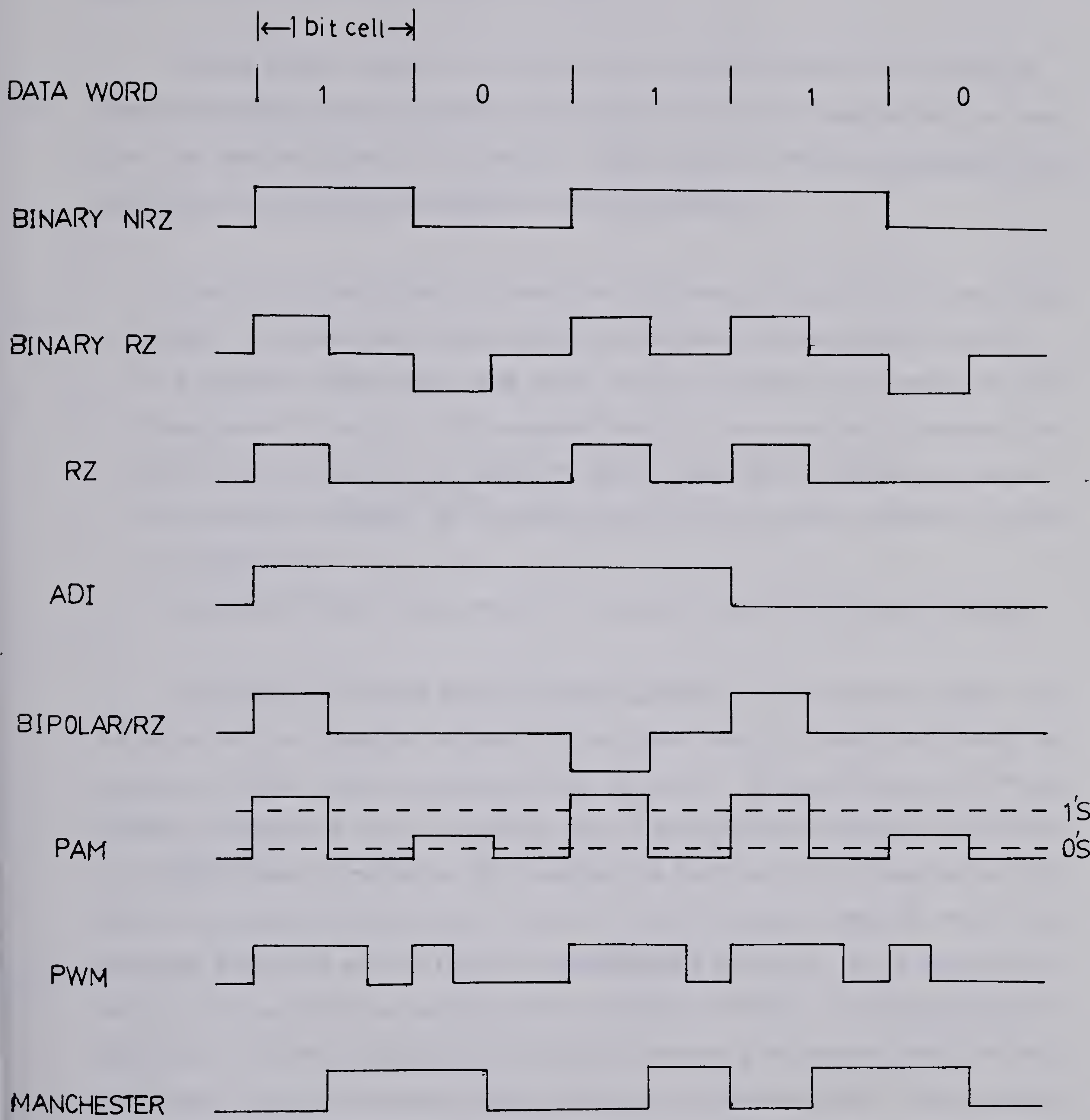


Figure 4.3 Various encoding schemes in baseband transmission

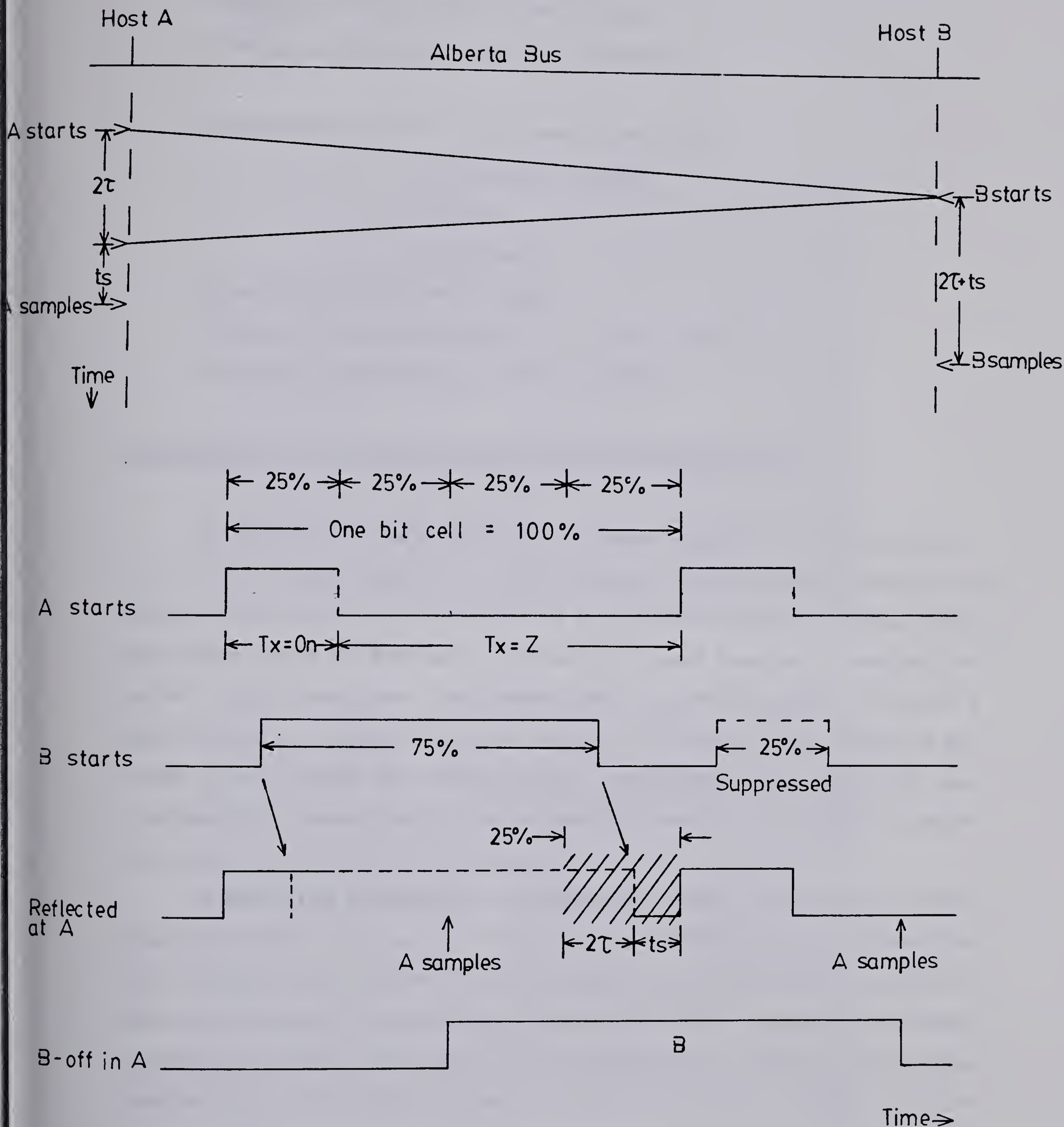
4.3.6 Data Rate calculation in Contention Window

Certain physical limits have been placed on the physical channel of the Priority Net . These revolve mostly around maximum cable length (or maximum propagation time), as these affect the time slots defined in the data link. These maxima in terms of propagation times were derived from the physical configuration model described here.

* A coaxial cable, terminated in its characteristic impedance at each end, constitutes a cable segment. A segment may contain a maximum of 500 meters of coaxial cable (RG11U).
* A maximum total coaxial cable length along the longest path between any two transceivers of 500 meters. The propagation velocity of the coaxial cable is assumed to be 0.65 C as a worst case (C is the velocity of light in vacuo; 300,000 Kilometers per second). The total round-trip delay (2τ) for all the coaxial cable in the system is therefore 5.12 μsec at the worst-case.
* A maximum number of hosts connected to a cable is 254 plus one for group addressing.

The following calculation shows the specific limitations on the contention window. Fig 4.4 shows the time-dependent behaviour of two hosts using the Priority Net during the contention windows (with time running down the page). We have 25% and 75% PWM encoding to represent '0' and '1' respectively. Host A at one end first transmits the dummy ID e.g., 00000000 after the ending flag F0 is detected: the initial part of this packet arrives at B after the propagation delay between A and B. Host B is ready to send the MSB (Most Significant Byte) of its source ID while A's transmission is passing by. At the middle of A's bit cell, A can sample the bus and know that B is sending a 75% pulse. The collision (backoff) detector in A will have an opportunity to recognize an interfering transmission from B (or from other hosts if more than one host transmits during the contention window). This is done by simply XOR'ing the outgoing data and the state detected on the bus, with a D type flip-flop to regenerate signals. In order to simplify the configuration, the 25% pulses from B (or other hosts) will be suppressed to minimize any mistrigger.

Pulse width calculation using 25% and 75% modulation standard is (as shown in shaded area of Fig 4.4) :



Note: Z=High impedance
τ=Propagation delay
ts=Settling time
B-off=Back-off

Figure 4.4 Time line of 2 hosts sharing the Priority Net

Propagation time delay (τ) for 0.5 Km=2.56 µsec

Allowing a settling time for signal (ts) = 2.56 µsec

Therefore 25% pulse = 2τ + ts (as shown in shaded area)

= 2 x 2.56 µsec + 2.56 µsec

= 7.68 µsec

= 8 µsec (app.)

Since 25% of the pulse width = 8 µsec

therefore 100% the pulse width (T) = 4 x 8 µsec = 32 µsec

Frequency for contention (F) = 1/T = 31.25 KHz

4.4 IMPLEMENTATION AND INTERFACING OF THE PRIORITY NET

The shared component of the Priority Net system consists of a single coaxial cable, e.g., RG-11U, typically strung in a meandering fashion through a building, perhaps in the ceiling or under a raised floor. As shown in Fig 4.5, individual computers or stations, connect to the cable by means of a BNC plug and adapter (tap); a small transceiver is connected at the tap with a cable running down to the interface which is located at the station. The use of a passive medium, and the lack of any active elements in the shared portion, combine to help provide a very flexible and reliable system. This approach also provides for easy reconfiguration of stations: machines can be moved from one point and reattached at another point without any need to take down the network.

In constructing an interface for a particular type of host, however, there are other design considerations. Interfaces can be built for several different machines: at high data rates they will usually be DMA devices. The precise design of the interface and its controller will reflect the architecture of the machine being attached. In a computer with user-programmable microcode, for example, the amount of actual hardware may be reduced, allowing certain operations to take place in the microcode. If there is no support at this level, it may be necessary to construct a more complex piece of hardware.

The most prevalent host in use is a flexible single user computer. In the experimental Priority Net system, the SDK-85 (Intel System Development Kit 8085) is the machine which

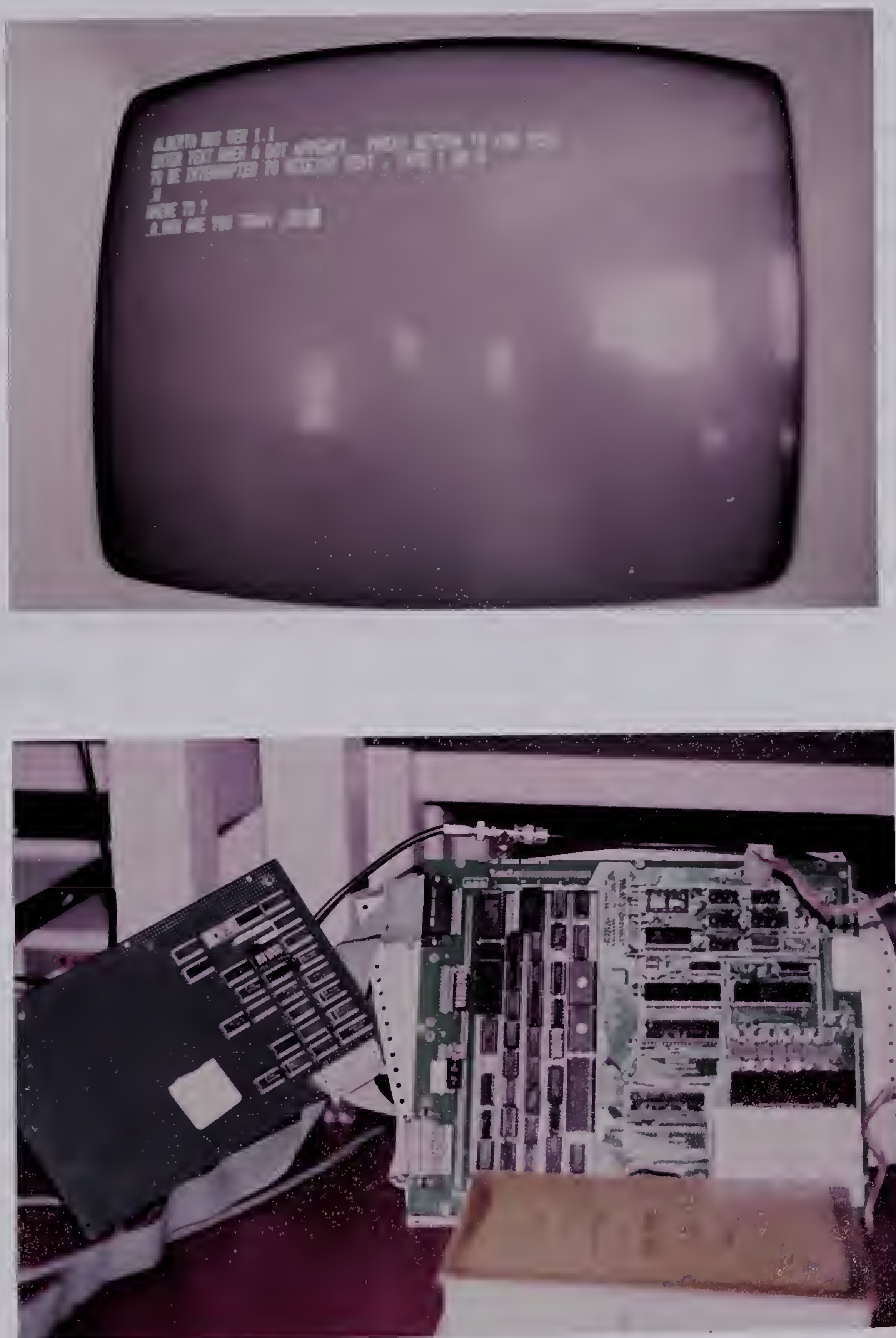


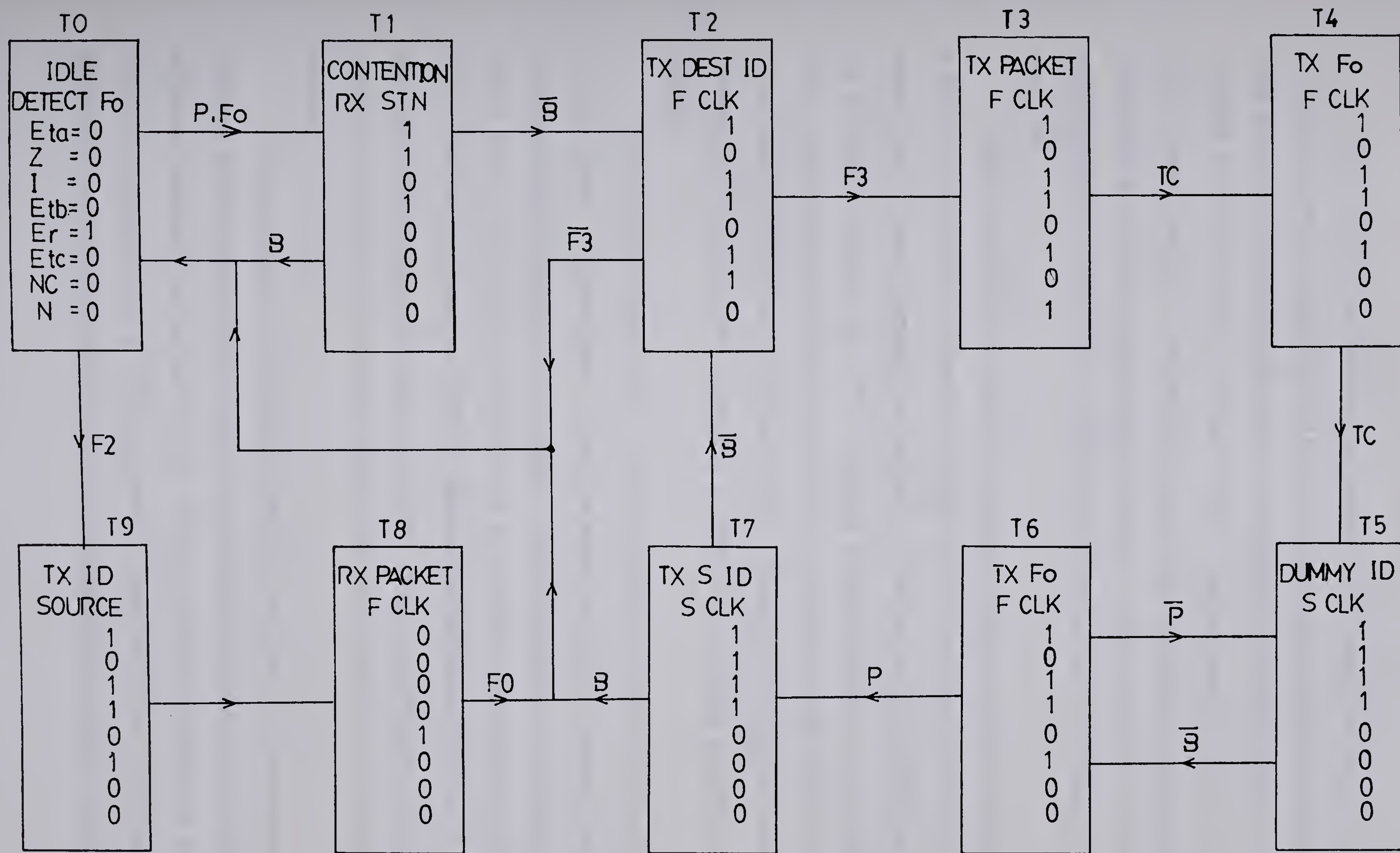
Figure 4.5 Photos of the Priority Net ,cable, tap, transceiver, controller and host

has served as the basic engine for running the testing and analysis programs. The SDK-85 contains all the parts for a single board 8-bit 8085 microcomputer system, and this has influenced the design of the Priority Net interface and controller, combining a modest amount of hardware with a small piece of software. We have chosen the Intel family instead of Motorola because Intel has better support for its DMA devices (several versions are available).

The interface consists of about 58 chips (excluding an one-chip CRC generator/checker) and is controlled with about 100 instructions of assembly language program. In effect, the interface runs like a DMA device: a user program can issue a start command ('return' key), and the DMA device will generate an interrupt upon completion of the appropriate action. For example, if the DMA controller is programmed to receive a 256 byte data packet, it will be interrupted to stop by the F0 (ending flag) of a shorter packet; there is no need for further DMA cycles. Similarly for transmission, the number of bytes to be transmitted will be the byte-count parameter of the DMA controller, and the device will generate an interrupt upon completion of these cycles;

Port C of the 8255A Programmable Peripheral Interface is designated as the control word used in the transceiver and interrupt system, Fig. 4.6 illustrates the control word used in different states.

- T0 - When system power has just turn on.
- T1 - If packet (P) is ready to send and ending flag (F0) is detected, the station then contends for the bus.
- T2 - There is no backoff signal after the contention window.
- T3 - There is a response 'Go-Ahead' signal (F3) from the receiving station after sending the destination ID.
- T4 - At the end of packet transmission, Terminal Count (TC) from DMA will be activated to indicate that it is necessary to send the ending flag.
- T5 - Transmits Dummy ID [00000000] after TC.
- T6 - Transmits ending flag (F0) again if there is no backoff signal after the contention window.
- T7 - Packet is ready again and the station then contends for the bus.
- T9 - After detecting its own ID, the station now sends its own Source ID as a response.



Note: Legend - Section 4.3

FIGURE 4.6 STATE DIAGRAM FOR CONTROL WORD IN THE PRIORITY NET

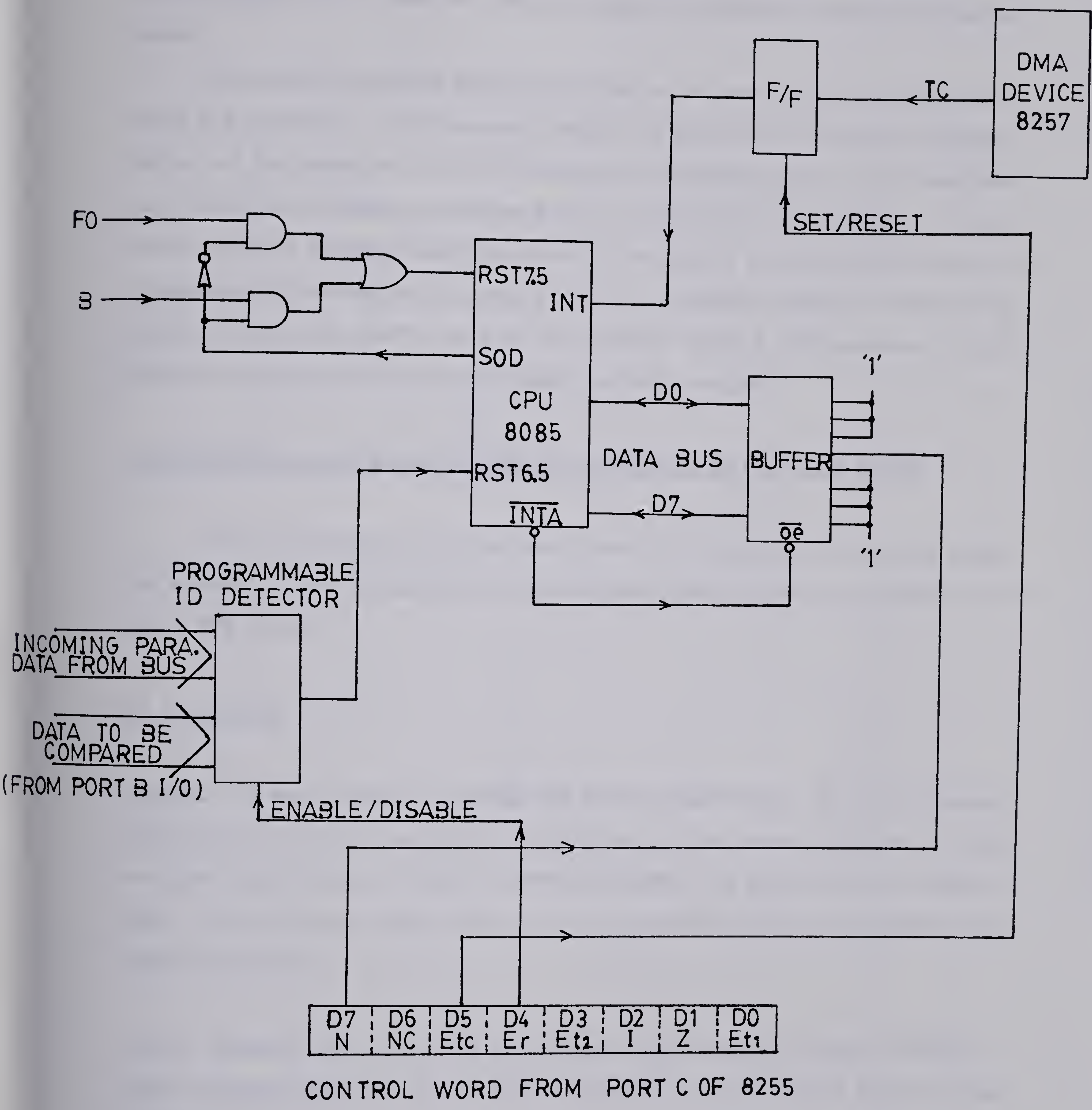
T8 - Gets ready to receive packet message.

Fig. 4.7 shows the basic interrupt system in the Priority Net where B (backoff) and F0 (ending flag) will be enabled by SOD (Serial Output Data line of the 8085) alternatively. A fixed priority that determines the order of recognization for all the incoming interrupts is set in the 8085 CPU; it is shown as follow: TRAP - highest priority, RST7.5, RST6.5, RST5.5, INTR - lowest priority. This priority scheme does not take into account the priority of a routine that is started by a higher priority interrupt. TRAP and RST 5.5 have been used in the monitor program so only RST7.5, RST6.5 and INTR are used in the design of communication controller.

RST7.5 and RST6.5 are maskable interrupts. When the system is powered on, the SOD is set to '0' and only F0 is allowed to interrupt the CPU by means of RST7.5. When there is a station about to send a message and contends for the bus, the SOD will be set to '1' enabling the B signal to interrupt the CPU. When the B signal is detected in the contention window, RST7.5 will be activated to interrupt the CPU. The station will then abort its transmission and try to contend for the next contention window. However, the station will proceed to send the destination ID and wait for a response if there is no B signal received in the contention window.

After the above steps, RST7.5 will be masked off and RST6.5 will be enabled to detect the "Go Ahead" response signal. Upon the arrival of RST6.5 interrupt, the CPU will then activate the DMA controller for transmission. Upon completion of transmission, TC (terminal count) signal from the DMA controller will be activated to interrupt the CPU by means of INTR. Following this last step, RST7.5 will again be enabled with SOD set to '0' to detect F0, and the whole process will repeat itself again. Since the detection of F0 and B is more important than the other interrupt signals, they have been wired with the highest priority interrupt e.g. RST7.5.

The transceiver is the interface between the controller and the common coaxial cable. It should provide ground isolation between the cable and controller, level conversion and a high impedance connection to the coaxial cable. However, there is a difference in the transceiver of the Priority Net due to the of CFMA protocol, as shown in Fig. 4.8. The transmitting clock is generated from the transceiver instead of the communication controller because multiple clock



Note: Legend - Section 4.3

Figure 4.7 Basic interrupt system in Controller

frequencies are required to implement the contention window. Phase encoding and decoding are implemented in the transceiver in order to suppress all 25% pulses during the contention window.

The controller interfaces with the transceiver to the internal bus of the processor to which it is connected. It performs serial-parallel and parallel-serial conversion, buffering, address and flag recognition, and CRC generation and checking (Fig 4.9). CRC generation and checking are performed in software using the standard CRC-16 polynomial. The next section contains a functional description of each of the parts of the Priority Net System, and considerations in the design or evaluation of each part. Appendix II shows the detailed circuit diagram of controller, interface to host, CPU, RS232C data link and transceiver. Fig 4.9 shows the functional block diagram of controller and user's interface.

4.5 FUNCTIONAL AND BLOCK DIAGRAM OF PRIORITY NET SYSTEM PARTS

This section povides a brief description of each of the parts of the Priority Net system, and Appendix I shows the controller / transceiver board circuit layout and the memory / IO map of SDK-85 host.

4.5.1 Transceiver

Transmit. The source current of the signal sent into the coaxial cable is -60 mA by connecting 4x74LS241N line drivers in parallel for a logic high signal. Sink current is 250 mA for a logic low signal and off-state is +20 uA. 10 percent to 90 percent rise and fall times are limited to 15ns $\pm$ 5ns which helps reduce reflections from the transceiver due to capacitances in the coaxial cable system.

Receive. Signals on the coaxial cable pass through a high impedance receiver (74LS241), a signal conditioning network (a D-type F/F), and finally an output buffer to drive the system data bus.

Backoff detect. The idle state of this line is ground and active state is either a 1 MHz or 31.25

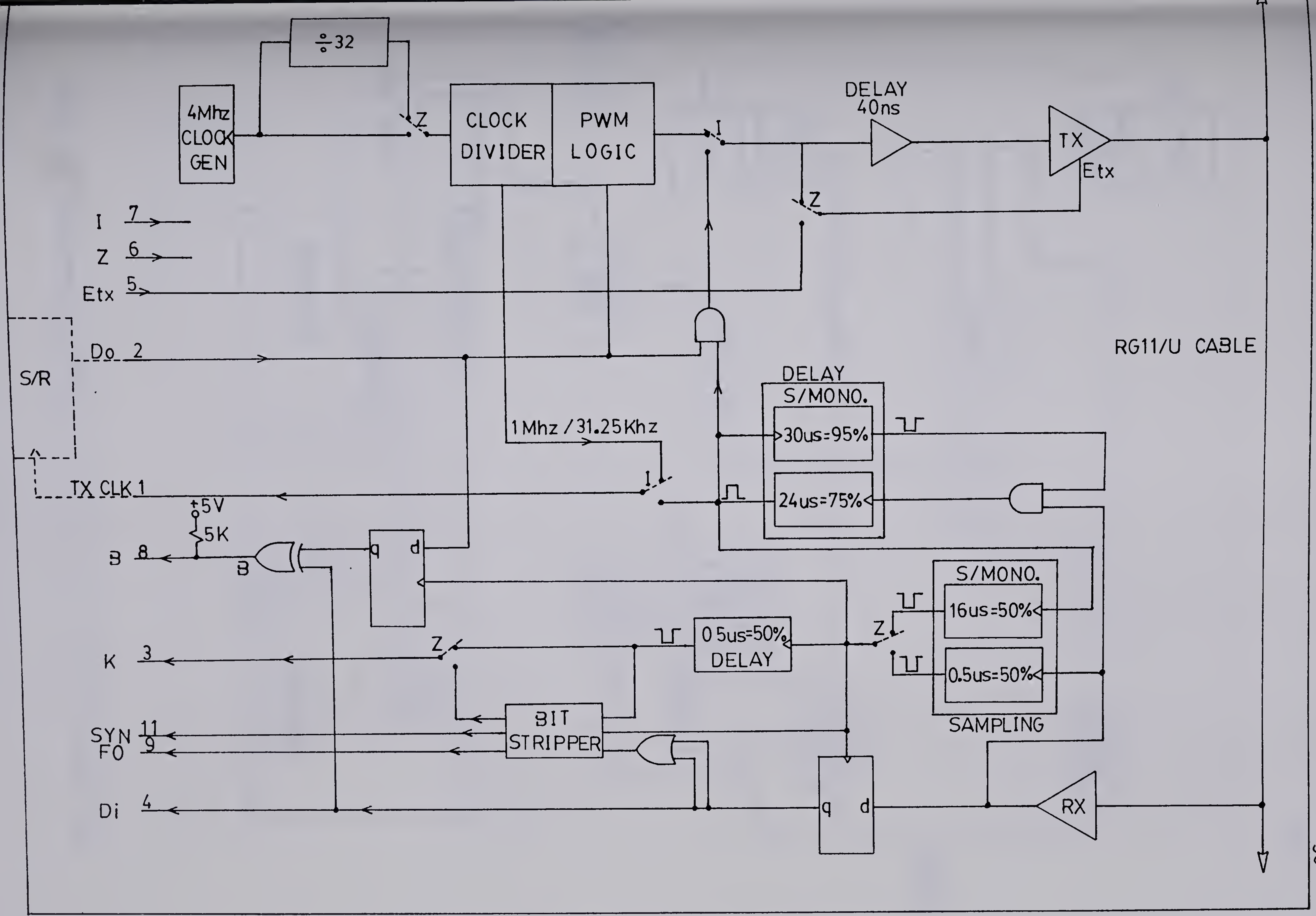


FIGURE 4.8 TRANSCEIVER BLOCK DIAGRAM

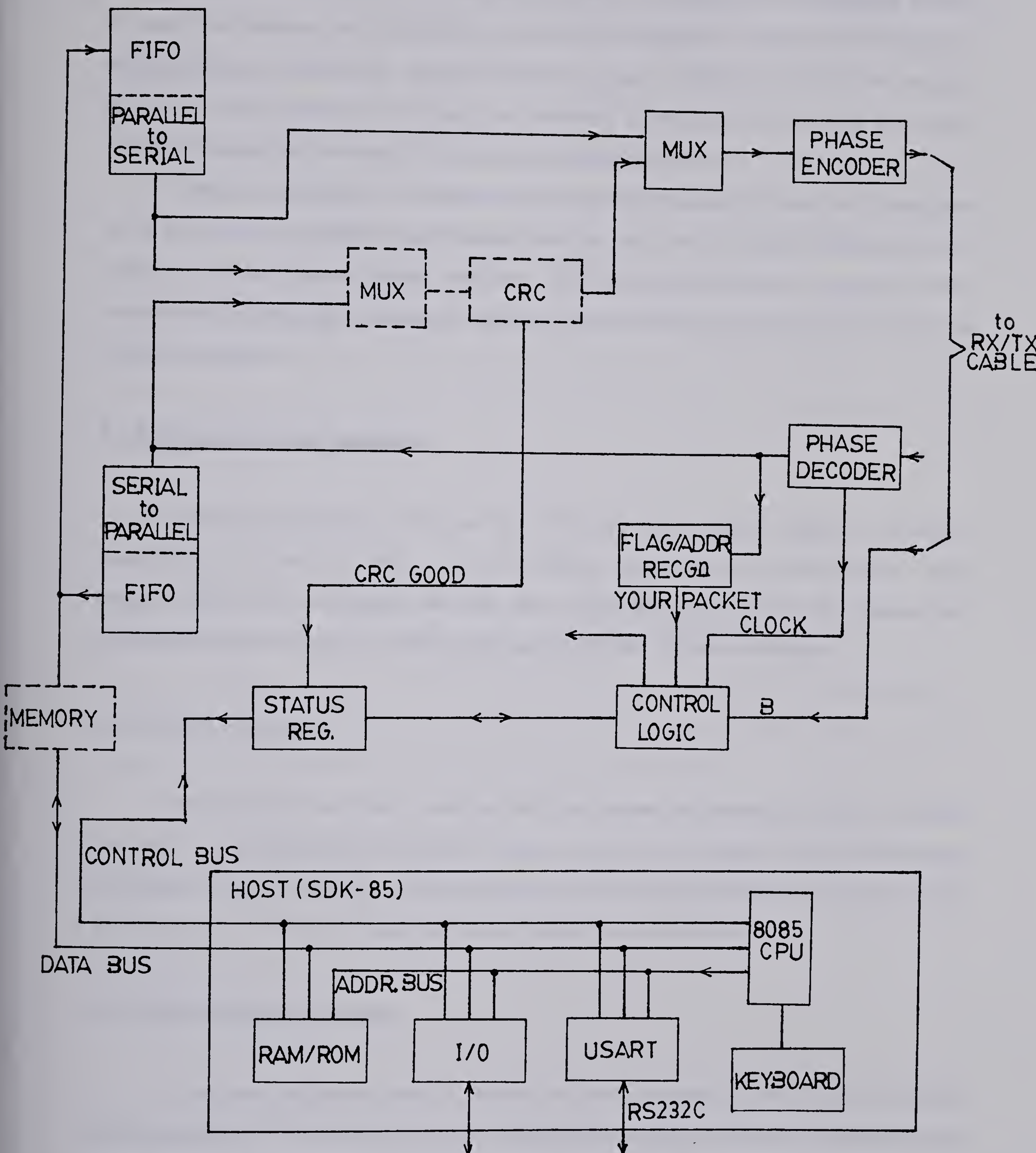


Figure 4.9 Functional block diagram of controller and host in the Priority Net

KHz waveform. The line goes to the active state when the transceiver is transmitting and one or more other stations are transmitting or when the transceiver is quiet and more than two other stations are transmitting. Backoff detection is done by XOR'ing (74LS136) the outgoing data and the state detected on the bus. The controller should ignore the backoff line, except when it is transmitting its source ID during the contention window.

There is a 40 ns delay for signals being transmitted because the transmitter should turn on 40 ns before the leading edge of signal waveform and turn off (high impedance) 40 ns before the trailing edge of signal waveform. This is particular useful to provide a sharp synchronized leading edge to trigger all receiving stations to shift out their source ID during the contention window.

4.5.2 Coaxial Cable and Terminator

The coaxial cable is a 75 ohm RG-11U cable with multiple shields to minimize susceptibility to strong RF fields. RG-11U cable is the cheapest one among similar types because most CATV companies use this cable. The ends of a coax cable segment are terminated with a five percent 75 ohm terminator to prevent reflected waveforms.

4.5.3 Address recognition

The controller must watch every packet which passes and determine whether to accept the packet. A programmable ID detector, which consists of 8X 2 input exclusive-NOR gates (74LS266), is used to compare the incoming data and the address to be compared with at port B of 8255 I/O. A J-K F/F is used to latch this signal for interrupt use.

4.5.4 CRC generation ad checking

A software program is used to provide the cyclic redundancy code (CRC) using the 16-bit polynomial. The choice of where to implement this function is based on expected traffic load for a given machine and available processor resource. We have only 4 stations and a limited size for each packet, therefore, lightly loaded traffic is expected - software can help to

reduce cost.

4.5.5 Buffering

The amount of buffering needed in a controller is determined by the latency and speed of the processor's I/O system. For I/O or DMA systems, whose transfer rates are less than the network bandwidth, full packet buffers are necessary in order to keep up the bit rate of network traffic. The buffers in the controller of the Priority Net are the memory in the host as the Intel 8257 DMA interface can handle up to a 3 Mhz data rate in the bus. Multiple buffers would be necessary in order to transmit or receive back-to-back packets at a data rate higher than 3 Mbps. Only 1K RAM memory (2X2114) is provided in this experimental Priority Net system.

4.5.6 Phase encoding and decoding

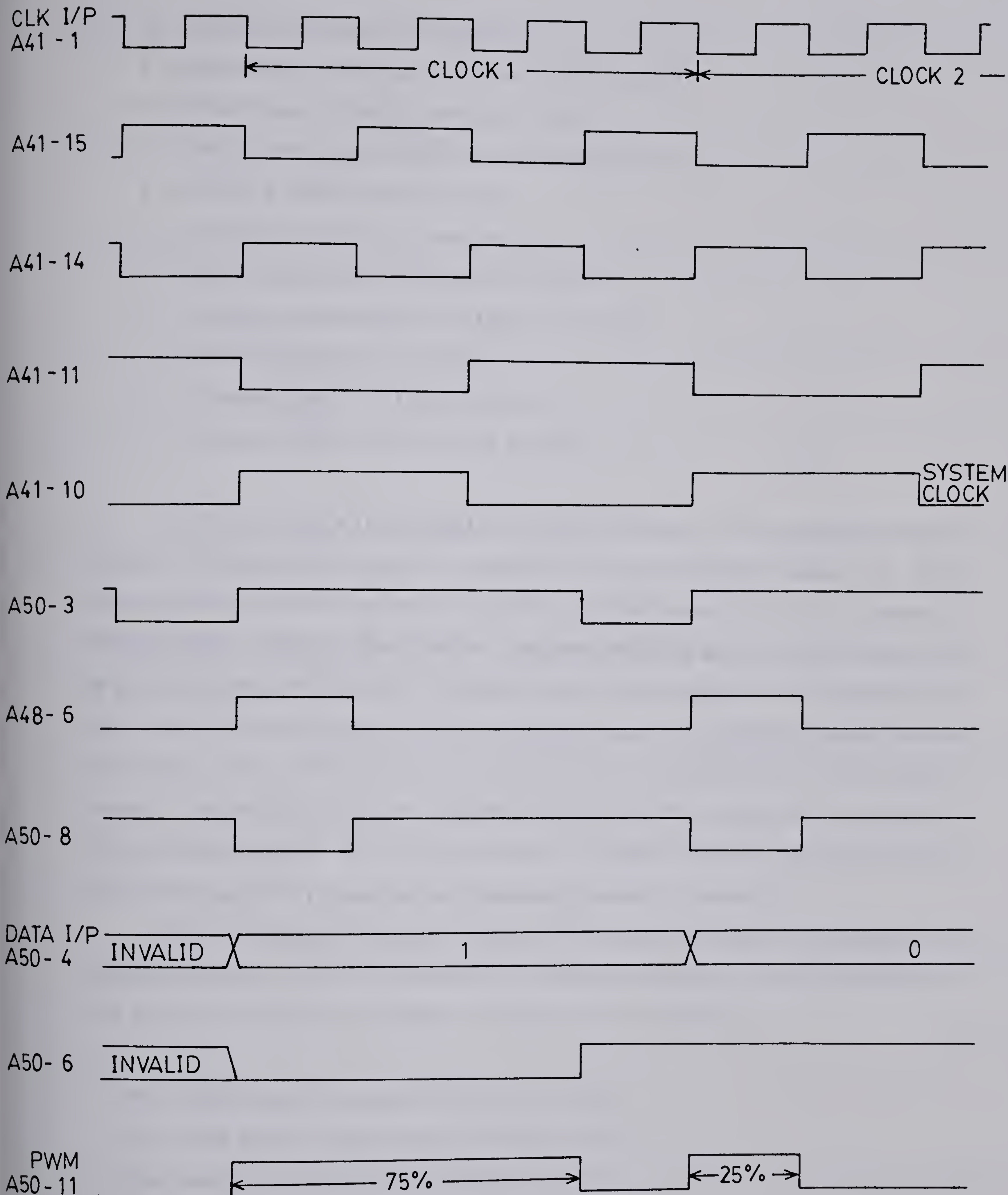
Pulse Width Modulation (PWM) encoding is used for data transmission on the Priority Net. It has 25 and 75 percent duty cycle to represent 0's and 1's respectively. Encoding is done in the transceiver by dividing the 4 MHZ clock into 4 phases and then followed by AND/NANDing the clock with the NRZ data. A 1 MHz bus clock is also derived from this circuit. Fig. 4.10 shows the detail waveform diagram of PWM circuit.

Clock and data extraction can be done by combining single-shot monostable multivibrators to generate 50% sampling cycle to clock the D-type F/F. A 90% duty cycle is also generated after every shot to prevent further trigger in one cycle period.

4.6 INTERFACE POINTS AND WAVEFORMS IN SYSTEM

Fig 4.11 illustrates the basic Tx (transmit) timing diagram where a signal (bytes) propagating through the controller and transceiver from the memory in the form of parallel data to the coaxial cable in the form PWM. The waveforms at point A to L represent as:

A = 1 MHz Tx clock from pin 10 of A41.



Note: A41 - 10 means IC A41 pin 10

Figure 4.10 Detail waveform diagram of PWM circuit

B = Eta &Etb from port C of 8255 (A33).

C = Ripple Carry (RC) from TX counter (pin 15 of A37).

D = DMA Request (DRQO) from pin 5 of A36.

E = DMA Acknowledge $\overline{\text{(DACK)}}$ from DMA (pin 25 of A7).

F = $\overline{\text{DACK}}$ + $\overline{\text{MR}}$ from pin 8 of A22.

G = Parallel microprocessor system data bus.

H = Serial output data from S/R (pin 13 of A24).

I = Transmitter enable signal (Etx) from pin 11 of A35.

J = PWM Signal from pin 11 of A50.

K = Terminal Count (TC) from pin 36 of A7.

L = Interrupt (INT) to CPU from pin 3 of A22.

As shown in Fig. 4.11, Eta and Etb (B) need to be set at '1' for transmission and the counter will generate RC (ripple carry) signals (C) for every eight clock pulses (A). Single byte transfers in the DMA operation is initiated by the DRQ0 signal (D) which is triggered by every RC signal. Once the DMA controller recognizes this DRQ0 signal, the DACK signal (E) is activated to reset the DRQ0 line. The DMA controller then generates "read" commands and byte transfers will occur between the shift register and memory. Through the parallel to serial shift register, the data from memory can now shift out in serial form (H). The first DACK signal (E) will set the control logic to activate the Etx signal (F), through this, the transmitter will be enabled precisely. After the transmission, a TC signal (K) from the DMA controller will interrupt the CPU (L) and the entire transmission process is terminated.

Fig 4.12 illustrates the signal (serial packet) propagating through the transceiver and controller from coax cable in the form of serial PWM to the memory in form of parallel data. It is a basic Rx (receive) timing diagram with point M to Y represents as:

M = PWM signal from coaxial cable [pin 12 of A46]

N = Clock signal (K) after stripper from pin 3 of A52

O = Input data in RZ form [Di] from pin 5 of A47

P = Di in parallel form after S/R (pin 3 to 13 of A23)

Q = SYN pulse from pin 8 of A36

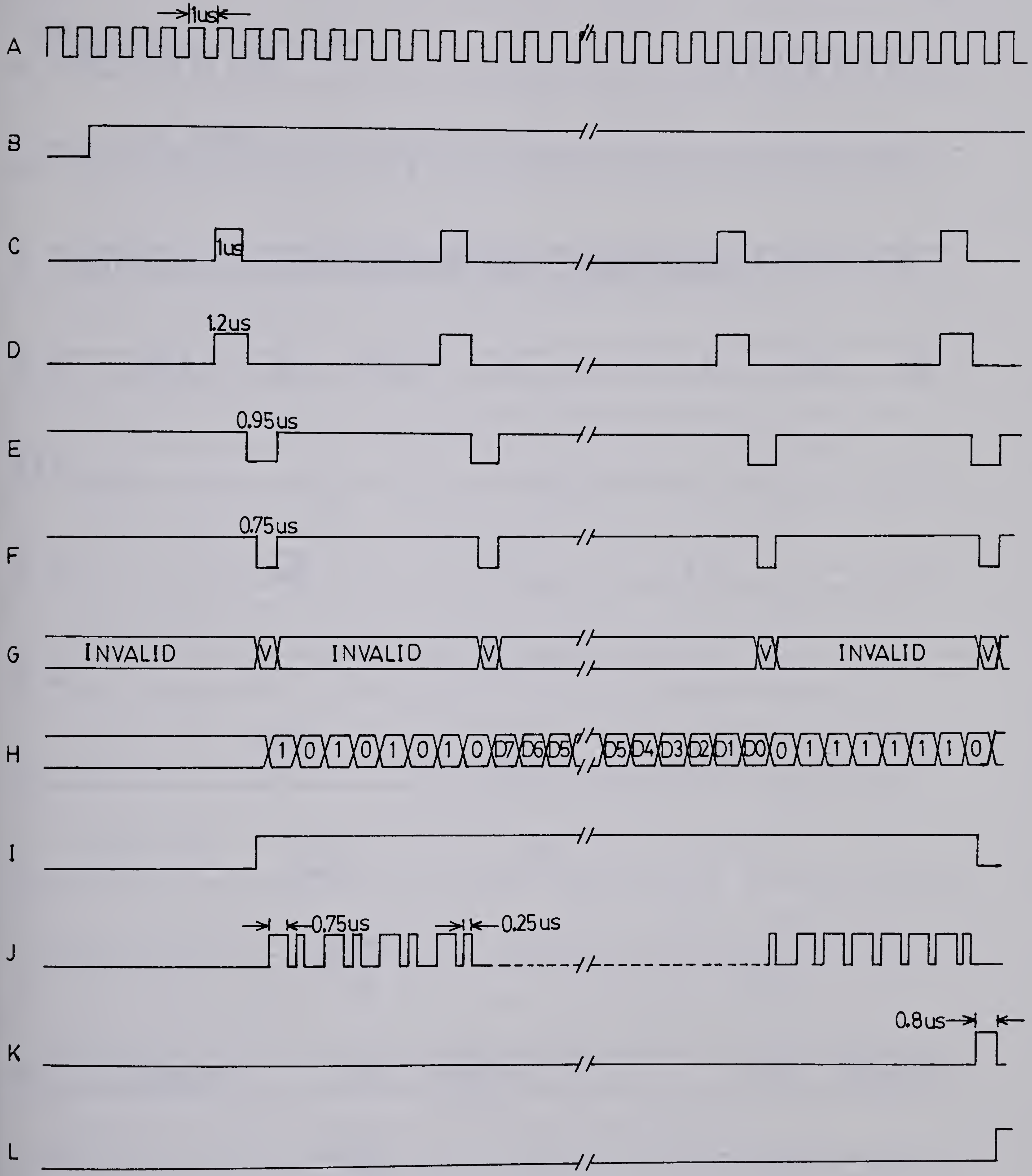


Figure 4.11 Basic Tx waveforms in comm. controller / transceiver

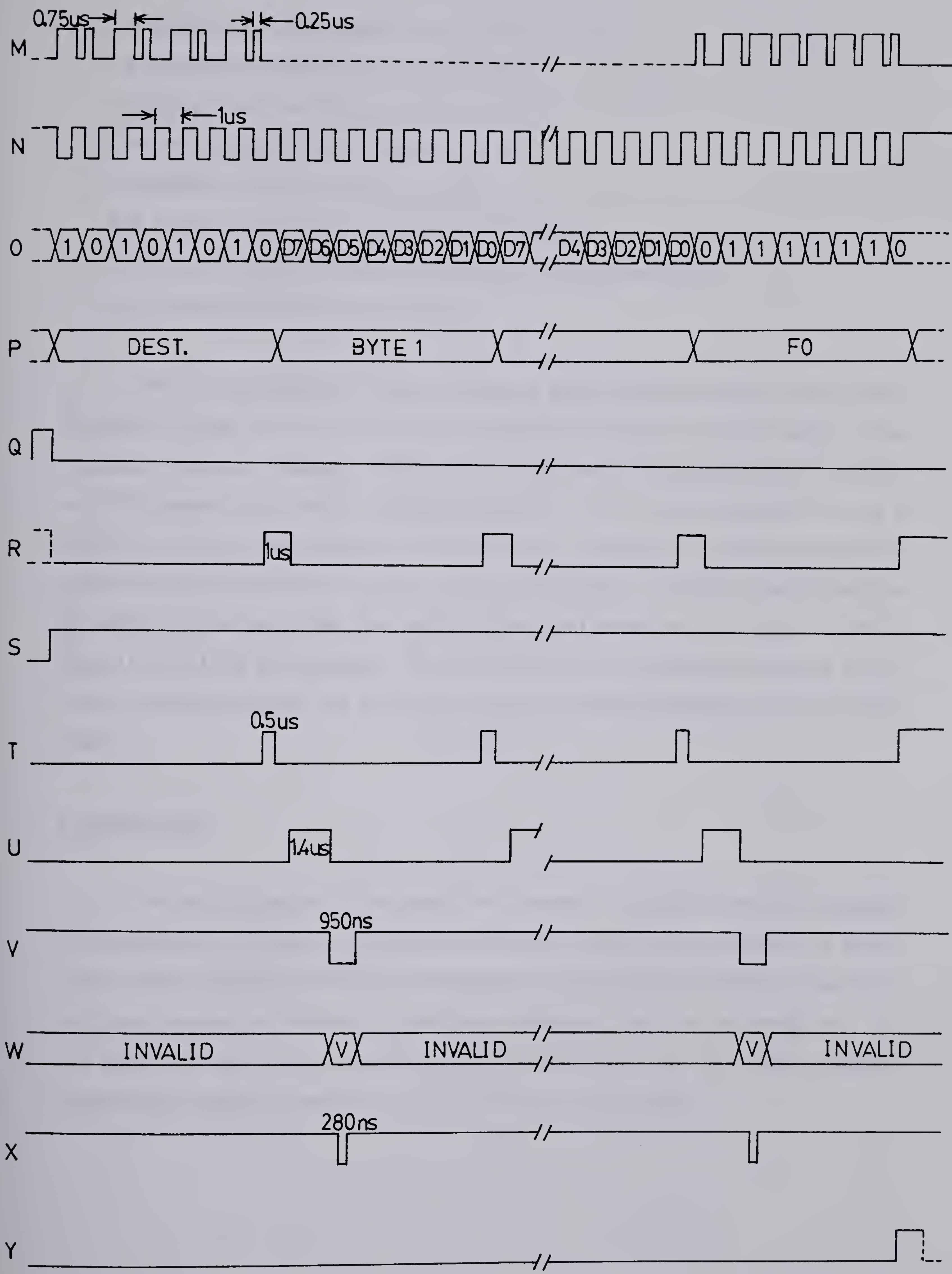


Figure 4.12 Basic Rx timming diagram for controller/transceiver

R = Ripple Carry (RC) from Rx counter (pin 15 of A8)

S = Receiver gate enable signal (pin 15 of A25)

T = Signal to latch parallel data (pin 11 of A21)

U = DMA Request (DRQ3) from pin 8 of A14

V = $\overline{\text{DACK3}}$ + $\overline{\text{IOR}}$ from pin 11 of A22

W = Parallel microprocessor system data bus from A9

X = Memory Write ($\overline{\text{MW}}$) signal to RAM from DMA (pin 4 of A7)

Y = Closing flag (F0) from pin 6 of A57

One of the advantages of using a modulation scheme that sends data and clock is that the clocking signal will not be generated in receivers if there is no data signals in the transmission medium. As shown in Fig. 4.12, a 1 Mhz clock (N) regenerated upon the arrival of PWM signals (M) is used to sample the data line. If the valid destination ID (P) is detected, the receiver enable signal (S) is then activated. Serial data (O) will be converted into parallel data (W) by means of a serial to parallel shift register. A counter is used to generate RC signals (R) for every eight clock pulses to latch the parallel data and trigger the DRQ 3 signal (U) for DMA byte transfers. The process will carry on until the ending flag F0 (Y) starts to interrupt the CPU. Fig 4.11 and 4.12 assume no stripping/stuffing process in the data stream.

4.7 SOFTWARE

The operating system of the Priority Net is written in Intel 8085 Assembler Language with cooperation from Alberta Microelectronic Centre to supply their equipment and advice. Only a simple operating system has been developed in this experimental stage and considerable more work is needed to develop a more effective operating system for the Priority Net. Fig 4.13 shows the flow chart of operating system and Appendix III shows some important demonstration subroutines used as part of the operating system program.

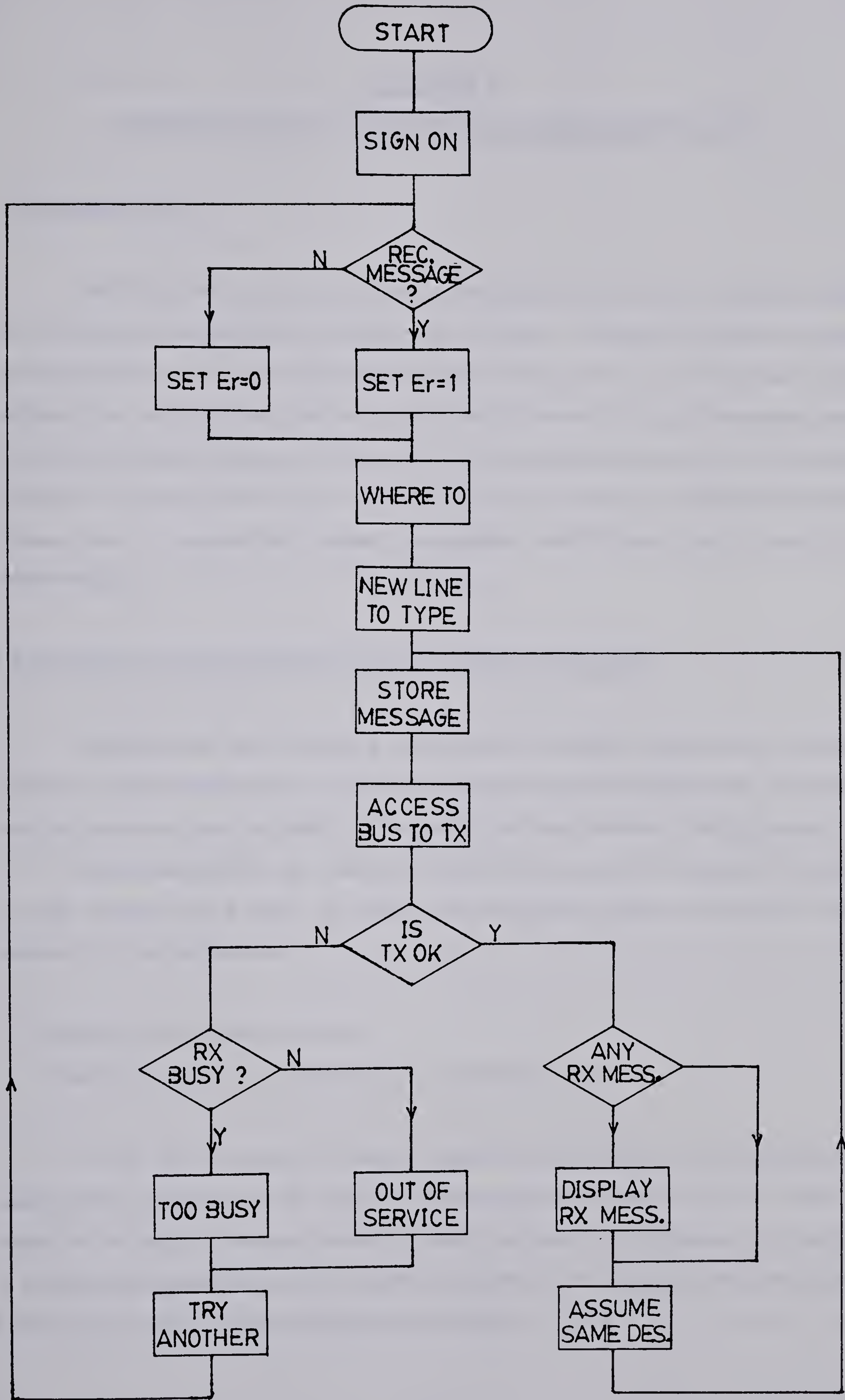


Figure 4.13 Basic flow chart of the operating system in the Priority Net

CHAPTER V

PERFORMANCE AND COMPARISON OF THE PRIORITY NET

5.1 INTRODUCTION

The Priority Net is the first Collision-free Multiple Access (CFMA) distributed control bus network to be implemented at the University of Alberta. Although 3152 bits of data have been transferred between two most widely separated stations over a 52.6 meters coaxial cable without error, the channel may not be error free for 500 meters or 1 Km. The assumptions of the channel efficiency with and without error will be evaluated separately. The following sections in this chapter also look at the Priority Net with respect to ISO model standard, average delay to access the channel, comparison with Ethernet and advantage of subnetworking.

5.2 PRIORITY NET WITH RESPECT TO ISO MODEL STANDARD

In recent years, there has been a proliferation of intelligent equipment and computers from many manufactures which are widely distributed throughout organizations. There have also been numerous private and public data networks developed to connect this equipment.

Communications between these systems and networks can only be possible if they abide by some common set of rules. In other words, distributed systems and networks require standards for communications:

* Standard protocols and interfaces.
* Standard approach to network design - a network architecture.

In 1978, the International Standards Organization (ISO) issued a recommendation to spark greater conformity in the design of communications networks and the control of distributed processing. The recommendation, which has gained wide acceptance, is in the form of a seven-layer model for network architecture, know as the ISO model for Open Systems Interconnection (OSI). The model suggests seven layers.

7 - application

6 - presentation

5 - session

4 - transport

3 - network

2 - data link

1 - physical

Physical layer - defines the electrical and mechanical aspects of interfacing to a physical medium for transmitting data.

Data link layer - facility to take raw transmission and transform it into a line (data frames) that are free of transmission errors to the network layers.

Network layer - accepts messages from the source host, converts them into packets, and directs them towards the destination.

Transport layer - to accept data from the session layer, split it up into small units, if necessary, and pass these to the network layer, and ensure that the pieces all arrive correctly at the other end.

Session layer - is a user's interface into the network, e.g., bridges the gap between the services provided by the transport layer and the logical functions running under the operating system in a user's node.

Presentation layer - convert data into formatted material on the screen.

Application layer - up to individual user, e.g., industrial robotic control.

Fig. 5.1 shows the design of the Priority Net LAN model related to ISO seven-layer model. In this ISO model, we have followed the terminology of DECNET which has been

implemented by Digital Equipment Corporation.

* Communication Interface Unit (CIU) - logically interface to the network. e.g., transceivers used in baseband LANs.
* Media Access Units (MAUs) - physical connection from CIU to transmission media. e.g., BNC N-series connector.
* Bus Interface Unit (BIU) - interface between node's internal bus and the CIU, e.g., Direct Memory Access (DMA) interface.
* Network Nodes (stations) - basic information processing units that are directly connected to a network e.g., Routing servers, Gateway server, Terminal servers, Print servers, File servers or just dumb terminals.

5.3 AVERAGE DELAY AND PERFORMANCE OF PRIORITY NET

Before we analyse the performance of the CFMA protocol implemented in the Priority Net, the following figures are summarized:

i) The number of stations connected to the Priority Net is 255 at most, which implies that an 8-bit contention window is required (e.g., 1 data bit in this window = 32 μsec).
ii) The Priority Net is running at 1 Mbps baseband (e.g., 1 data bit = 1 μsec).

5.3.1 Average delay

During the lightly loaded state (Fig. 4.2b), the last transmitting station will just keep on sending the ending flag and Dummy ID. The average delay time that a station has to wait before starting transmission of its Source ID (in the worst case) will be: when a message is ready to be sent, the current slot will be somewhere in the middle of the contention window. The average delay time will be half the sum of the contention window and ending flag. In this case, the time for the 8-bit contention window is 32 μsec x 8 = 256 μsec and the 8-bit ending

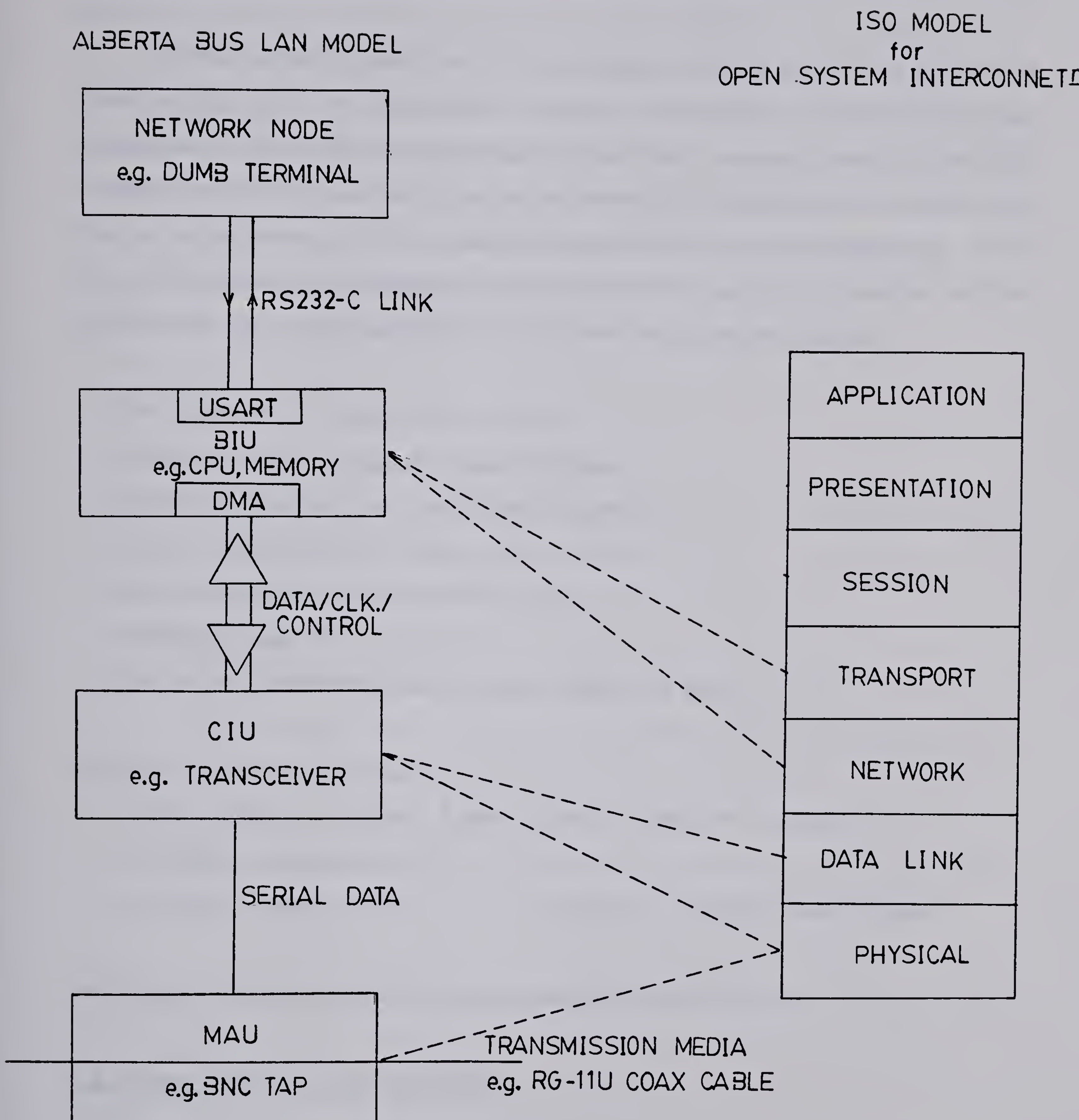


Figure 5.1 The Priority Net LAN model related to ISO seven-layer model

flag is 1 μsec x 8 = 8 μsec. Therefore, the average delay will be (256 μsec + 8 μsec) / 2 = 132 μsec.

During the heavily loaded state, when the system is running at maximum capacity (as shown in Fig. 4.2a), the average delay time that a station has to wait before starting transmission its Source ID (in the worst case) will be: when a message is ready to be sent, the "current" slot will be somewhere in the middle between two ending flags. The average delay time will be half the sum of all the overhead and packet time between two ending flags. In this case, the time between two ending flags will be the sum of the time for F0, contention window, DEST, RESP, SRC, packets and CRC (Fig. 4.2a) and their respective values are:

F0 = ending flag = 1 μsec x 8 bits = 8 μsec
Contention window = 32 μsec x 8 bits = 256 μsec
DEST = destination ID = 1 μsec x 8 bits = 8 μsec
RESP = response signal = 1 μsec x 8 bits = 8 μsec
SRC = source ID = 1 μsec x 8 bits = 8 μsec
Packets = 1 μsec x N
CRC = cyclic redundancy code = 1 μsec x 16 bits = 16 μsec

Therefore the average delay will be

(8 μsec + 256 μsec + 8 μsec + 8 μsec + 8 μsec + 1 μsec x N + 16 μsec) / 2
= (304 μsec + 1 μsec x N) / 2
= 152 μsec + 1 μsec x N / 2 where N = number of bits in a packet

For example, if N equals to 1000, then the average delay will be 652 μsec.

5.3.2 Channel efficiency of the Priority Net

This CFMA protocol implemented in the Priority Net provides no acknowledgement at the end of each packet, therefore, it is ignored throughout the calculation of the channel efficiency. However, the RESP (response) handshake signal must be received before the transmission of TEXT, it has been treated like an acknowledgement throughout the following

calculation. Although the design of Priority Net is based on a 500 meters long coaxial cable, the actual implementation has been tested only on a length of 52.6 meters. The basic approach for determining the channel efficiency of this CFMA protocol is to determine the ratio of bandwidth used by TEXT to the bandwidth used to send the statistically average frame. Statistically average frame means that retransmission and timeout will be considered. The following notation are derived from Fig. 4.2 and used in the following calculation.

Ct = channel capacity for TEXT in Mbps e.g., 1 Mbps

Cc = channel capacity in contention window in Kbps e.g., 31.25 Kbps

D = number of bits per "DEST" byte e.g., 8 bits

E = number of bits per contention window e.g., 8 bits

H = Number of bits in header e.g., 8 bits Source ID

I = interrupt and station service time + propagation delay e.g., 2.5 μsec for 0.5 Km cable

M = number of data bits per frame

Pd = probability of "DEST" byte lost or damaged

Pr = probability of "RESP" byte lost or damaged

R = number of bits per "RESP" byte e.g., 8 bits

T = timeout interval to wait for response after sending "DEST" byte e.g., 3 μsec at present implementation

U = channel efficiency

Z = mean number of handshake retransmissed per frame e.g., contending for the bus, sending "DEST" and waiting to receive "RESP"

Note: Assume TEXT is error-free, because there will be no ACK (Acknowledgement) provided in this protocol.

* Denote the time that the sender begins to contend for the bus
* At time E/Cc, the last bit in contention window has sent
* At time E/Cc + D/Ct, the last bit of "DEST" has sent
* At time E/Cc + D/Ct + I, the last bit of "DEST" has arrived at receiver station
* At time E/Cc + D/Ct + I + R/Ct, the last bit of "RESP" has sent from the receiver

* At time $E/Cc + D/Ct + I + R/Ct + I$, the last bit of "RESP" has arrived the sender
* At time $E/Cc + D/Ct + I + R/Ct + I + M/Ct$, the last bit of "TEXT" has sent
* At time $E/Cc + D/Ct + I + R/Ct + I + M/Ct + I$, the last bit of "TEXT" arrived at receiver

Total bandwidth occupied by this frame

$$= Ct \times [E/Cc + D/Ct + 3I + R/Ct + M/Ct]$$

$$= E/Cc \times Ct + D + R + 3ICt + M \qquad \text{where } Ct/Cc = 32$$

Since the number of data bits actually transferred is M, the channel efficiency U will be $M/[E(Cc/Ct) + D + R + M + 3ICt]$.

If the channel is not error free, the sender will timeout T sec after the last bit of "DEST" has been sent. Thus, wasted transmission occupies $(E/Cc + D/Ct) \times Ct + Ct \times T$ bits of channel capacity. If Z is the mean number of handshake retransmissions per frame, then $Z[(E/Cc + D/Ct) \times Ct + Ct \times T]$ will be the mean wasted channel capacity.

The probability of success in having a handshake is $(1 - Pd)(1 - Pr)$ which means that "DEST" and "RESP" are correctly received. On the other hand, the probability of failure is $L = 1 - (1 - Pd)(1 - Pr)$. An expected number of transmission per handshake is 1/probability of success or $1/(1 - L)$ and mean number of handshake retransmissions per frame is $Z = L/(1 - L)$. Then the channel efficiency U will be

$$= \frac{M}{\{[L/(1 - L)](ECt/Cc + D + CtT)\} + [ECt/Cc + D + R + M + 3ICt]}$$

If the channel is error free, then the channel efficiency will be $U = M/[(ECt/Cc) + D + R + M + 3ICt]$, and its channel efficiency is shown in Fig. 5.2 where I is assumed to be 2.5 μsec for 500 meters of cable in this experimental stage. Therefore, U can be rearranged to be $M / (279.5+M)$. Now, as an example, Pd and Pr are assumed to be 0.1, the channel efficiency will be lower than error-free channel and its efficiency is shown in Fig. 5.3. T is fixed to be 3 μsec as the maximum wait time for 500 meters long cable and, therefore U can be rearranged to be $M / (342+M)$.

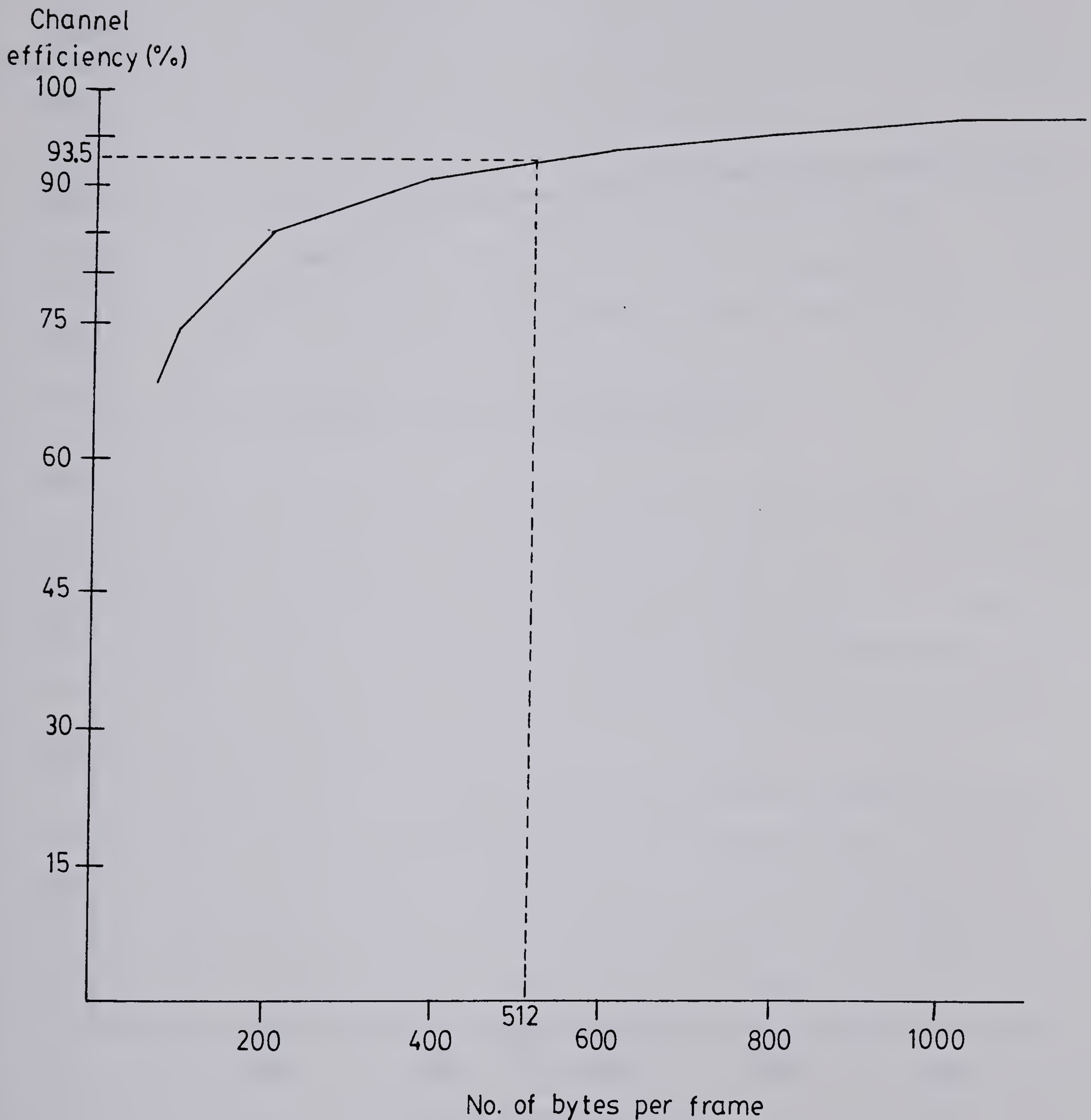
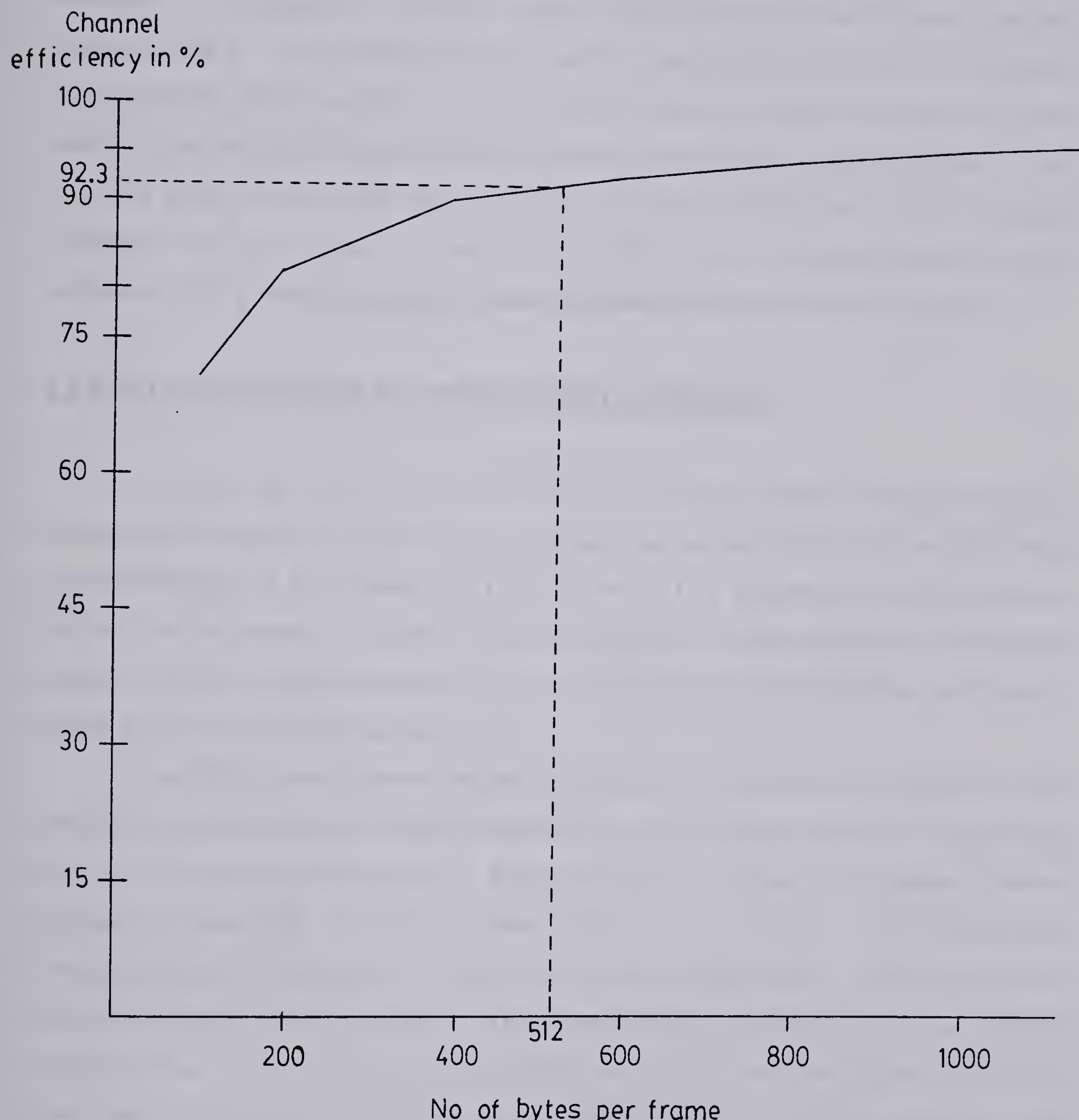


Figure 5.2 Channel efficiency of the Priority Net assuming error free



Legend: at section 5.3

Figure 5.3 Channel efficiency of the Priority Net assuming Pd and Pr equal 0.1

The average throughput of the network is defined to be the number of packets (message) per second that a channel can handle. No optimum packet size for the Priority Net has been determined yet and it is assumed to be 512 bytes (4096 μsec for 1 Mbps) for the calculation of throughput. For every packet transmission, there will be some overhead associated with it. The overhead for every packet in the Priority Net will be F0, contention window, DEST, RESP and SRC. Their respective values are shown in Section 5.3.1 and therefore the overhead per packet will be the sum of these which is equal to 288 μsec. Every 512 bytes packet occupies 4096 μsec for its data associated with 288 μsec overhead. Average throughput will be 1/(time for a packet) or 1/(4096 μsec + 288 μsec) which is 288.15 packets/sec. Note that different packet sizes will result in different average throughput.

5.4 THE COMPARISON OF PRIORITY NET WITH ETHERNET

As we can see that the channel efficiency of Ethernet, which is shown in Fig. 5.4, depends on the number of stations ready to contend for the bus [1] [36]. On the other hand, channel efficiency of the Priority Net (Fig. 5.2 and 5.3) is independent of the number of stations. As the number of stations in Ethernet system grows, channel efficiency will decrease. However, there is a common tendency in both the Priority Net and Ethernet that, as the size of packet grows, channel efficiency increases.

It is difficult to compare two different protocols such as Ethernet and Priority Net, but their basic performance can be roughly concluded from their channel efficiency. As seen from Fig. 5.4, 64 stations contending for the Ethernet cable with average 512 bit packets, channel efficiency is around 82%. In Fig. 5.2, channel efficiency of the Priority Net is 93.5% with the same parameters. Note that Fig. 5.2 is only for 0.5 Km length of cable at 1 Mbps and Fig. 5.4 is for 1 Km length of cable at 10 Mbps. The channel efficiency in Fig. 5.2 and 5.4 are assumed to be error free. At this point, approximate conclusion can be drawn that efficiency of Priority Net is better than Ethernet. If the contention window in Priority Net can be reduced by using hybrid circuits (baseband mixed with broadband) and multilevel modulation schemes, a system with its efficiency higher than Ethernet but independent of the number of stations ready to transmit can be achieved.

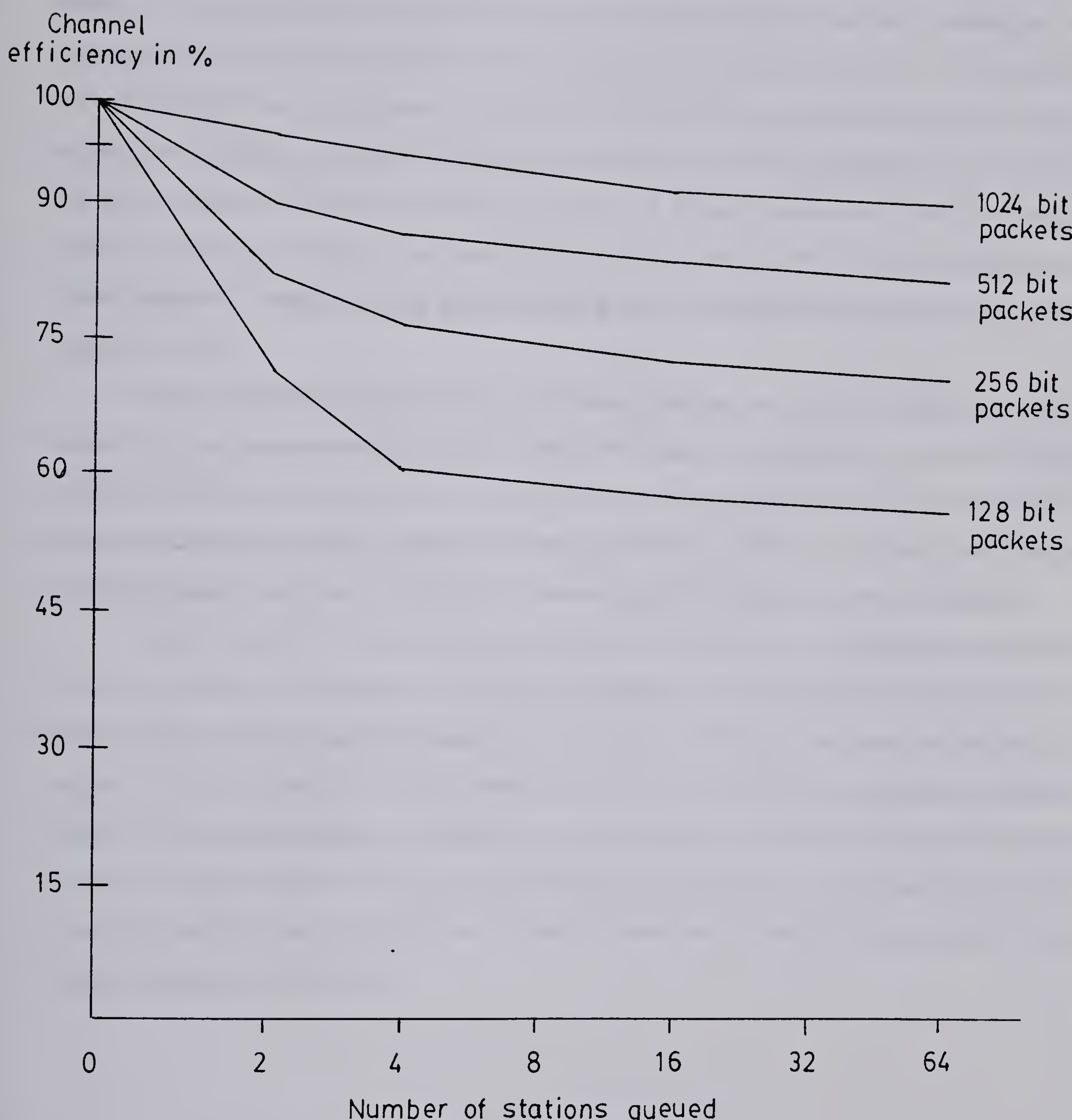


Figure 5.4 Channel efficiency of Ethernet at 10Mbps with 1 Km cable (Adapted from[1])

5.5 THE SUBNETWORK CONCEPT TO INCREASE TRAFFIC DENSITY

A local area network means a collection of subnetworks which are interconnected by bridges. These subnetworks may be implemented with different network topologies or transmission rate but their packet sizes and software protocols must be identical. In order that these subnetworks can be addressed to each other, a single overall unique address space should be provided. Bridges are midway in complexity between the gateway processors and repeaters and their related functions can be found in Fig 5.5. A bridge interconnects two subnetworks which are physically adjacent, and selectively repeats packets between them according to a "filter function". Speed-matching function can be done in bridges because they buffer all the repeated packets.

Every subnetwork must have its own advantage and can be utilized in a single local area network by the subnetworking concept. A network could be composed of a contention bus subnetwork such as the experimental Priority Net and a ring subnetwork with the advantages of easy configuration and greater geographical span respectively. These two subnetworks could be of different speeds, however, the bridge in between them will buffer their speed difference.

Subnetworking will handle traffic growth in an orderly way. By spliting the network into two or more interconnected subnetworks, efficiency of a heavily loaded network can be improved when a higher speed network is not available. Owing to the selective property of bridges, the traffic density on each subnetwork will be less than the original monolithic network. That is, partitioning of the hosts into subnetworks can be done in a way that a group of hosts with higher traffic density among themselves are tied into the same subnetwork, traffic across the bridges will be minimized, and a greater portion of all packets will stay within their original subnetwork [5] [37] [38].

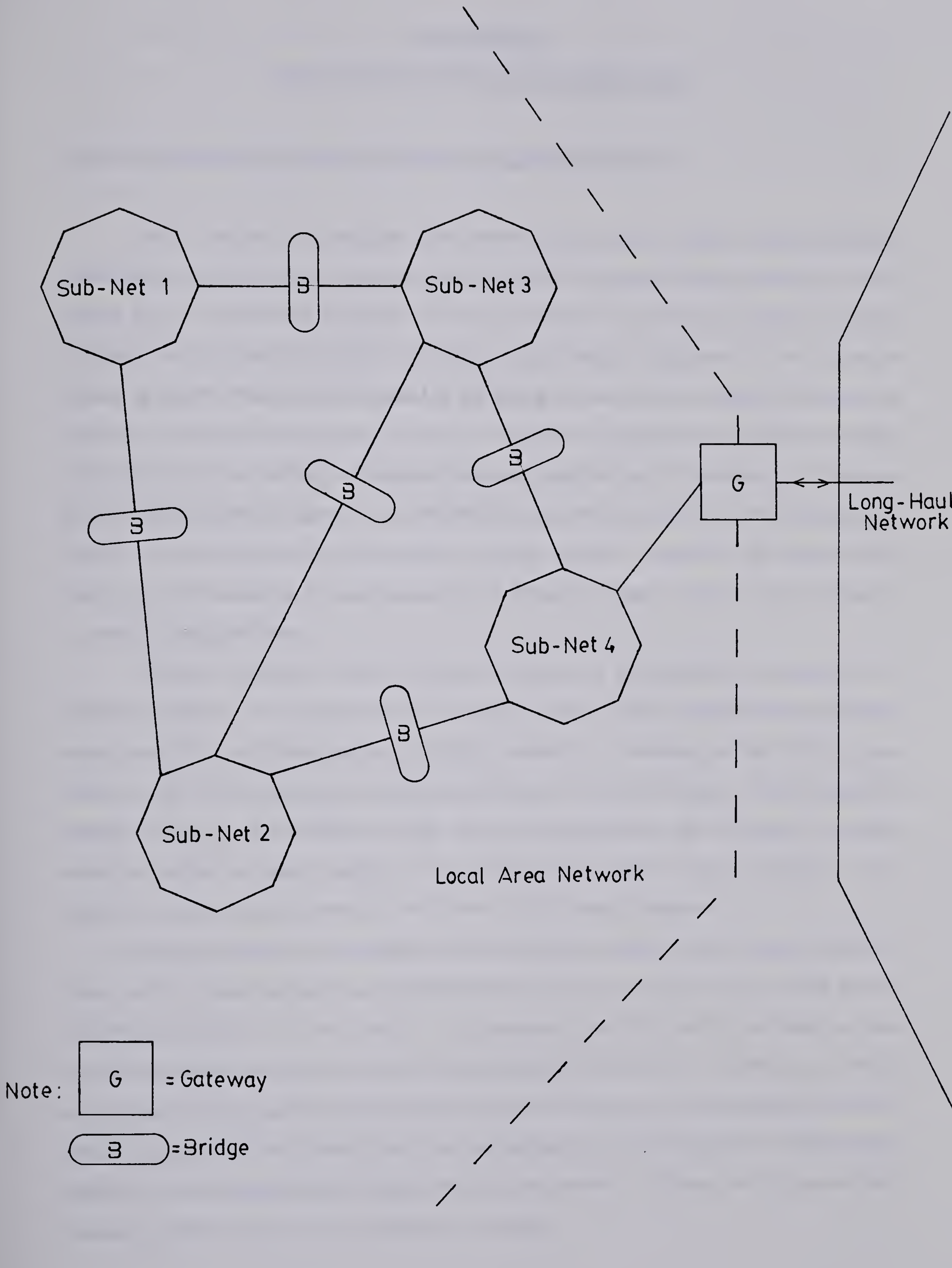


Figure 5.5 The subnetwork concept (Adapted from [5])

CHAPTER VI

CONCLUSIONS AND FUTURE DIRECTIONS

6.1 CONCLUSIONS FOR THE EXPERIMENTAL PRIORITY NET

Due to the use of propagation time between the two most widely separated stations, multiaccess contention control bus networks are limited in spanning distance similiar to token passing ring. As mentioned in Section 4.3.6, the frequency for contention window in Priority Net needs to be adjusted according to different cable lengths. The time for the contention window in Priority Net will be increased if the length of the network extends; this limits the distance that Priority Net can span. However, its reliability is greatly improved by the protocol of Priority Net which provides a handshake response signal before its transmission; in the sense that no other stations are allowed to contend for the bus without detecting the ending flag and Dummy ID, the chance to abort transmission is greatly reduced. Therefore, the Priority Net is believed to be well suitable for a small area where reliability is more important then efficiency, e.g. banks or small offices.

The main factor that limits the channel efficiency of Priority Net is the length of the contention window. The experimental LAN circuit uses a PWM (pulse width modulation) scheme with 25% and 75% pulse widths digits respectively. Sampling of the PWM signals occurs at the 50% or midpoint from the leading edge of the PWM digits. By changing the modulation lengths, from 25% and 75%, and the sampling from the 50% point, a shorter contention period is possible which in turn will result in higher channel efficiency. The tradeoff is a more complex transceiver with more critical timing constraints.

Ground isolation in the multiaccess bus networks also determines the system reliability. There are two ground references in the Priority Net: the common coaxial cable shield and the local ground associated with each station. It is important that these are not tied together, since one local ground may differ from another local ground by several volts. Connection of several local grounds to the common coaxial cable could cause current to flow through the cable's shields. Ground isolation transformer must be provided in every transceiver to eliminate this problem. Since the experimental Priority Net has been tested in a distance of 56.4 meters with 4 stations, ground isolation is not provided at this stage.

Distributed initialization and recovery must also be considered in the Priority Net. Since the last transmitting station may fail to keep on sending an ending flag and Dummy ID, software must be provided to keep tracking the status of the bus for network reinitialization. In order to take account of this problem, considerable work is needed to develop a more effective operating system for the Priority Net.

Finally, voice can be integrated into the Priority Net system using voice coding scheme and the detail will be discussed in the next section.

6.2 THE EVOLUTION OF PACKET VOICE AND LOCAL NETWORK

It is no doubt that voice communication through telephone lines and data communication (local network) through cables are important installations in modern society. As we stroll around the buildings in our campus, we can tell that it is very uneconomical to have these two systems separately installed, and nowadays, there is an increasing techniques for the integration of voice and data services.

The integration can be done in two ways, either by transmitting data through the phone system, or carrying voice through the data system. The PBX manufacturers have fulfilled the former integration. The approach is to carry data through a digital PBX (private branch exchange). This configuration using star topology, though seems to be very attractive, it shows some weaknesses in reliability and capacity problems when serving as a general purpose local network. Carrying voice traffic through the packet switch data system is not an easy job either, because the following specification must be achieved.

* With digitized voice broken up into packets, the system must send packets frequently enough to minimize possible delay to a tolerable limit.
* Every telephone handset would be equipped with the processing capability to produce digitized voice, using one of many different voice coding schemes.
* Calls within the network should be connected without the use of a separate controller.
* External calls must accomplish a header which is used to generate a set of dialers connected to regular telephone trunks.

Despite the above mentioned problems, there are several other important design decisions must be considered, such as: silence detection, blocking probability, voice coding scheme, network bandwidth and communication protocol. With the development of multi-channel broadband networks, the integration of voice and data services seems to be a very workable approach, and requires further study.

However, baseband networks (e.g., the Priority Net) can still support a few hundred telephones by using a sophisticated access control scheme. Every sign-on telephone can be allocated a time slot according to their ID to send their voice packet after the arrival of an ending flag. All sign-on telephones can access the network with higher priority than hosts. If all sign-on telephones occupy the available bandwidth in the network, there will be no contention window flowing in the bus, which means that no host can access the network. Each port must be able to analyse the status of the bus and to distinguish which time slot has been allocated to them. This assigned time-slot technique is a very workable approach and merits further research since it greatly reduces the overhead of the network.

6.3 THE IMPLEMENTATION OF LANs IN MANUFACTURING

Over the last few years industrial control systems in common with many other forms of electronic equipment, have exhibited a trend away from centralized control towards far greater use of distributed intelligence. However, although numerous advances have been made in the field of control which has made distributed systems an attractive solution, similar advances have not been apparent in the communication techniques employed between these systems. Indeed, the local use of extremely sophisticated computer controls has placed a heavier burden on the existing communication methods which mainly consist of many dedicated point to point serial data links.

These methods are unlikely to satisfy the growing demand of modern industrial systems for all forms of information transfer. Some US process control equipment suppliers have noted this communication deficiency and have adapted the latest developments in local area computer network technology to suit the particular requirements of process control. Until recently, Programmable Controllers (PCs) have typified the communication problem. While individual PCs are now becoming extremely powerful control devices, most lack a coordinated

approach to communication. Therefore, some manufacturers have now made what would appear to be a significant development, in view of the central role of PCs in industrial control by introducing a local area computer network to interlink its range of PCs. By doing that, a network supervisory station and network file server must be incorporated in network system in order to access the program memory in each of the PCs.

Research programs using networks in robotic production systems are currently underway in some universities and research institutes to investigate the design of robotic structures for low cost automation using modular components. This program complements work also being done in other application areas notably noncontact inspection and arc welding employing several different types of commercially available industrial robots. The potential advantages of employing robots coupled to a comprehensive communication network are numerous, such as,

* Cost reduction in robot control system. Since the robot control system has access to the resources of the total network, its cost can be reduced as it is no longer necessary to provide bulk storage and hard copy locally.
* Increased capability. Quality assurance, productivity and maintenance data to be stored and analysis either locally or remotely at some data collection point.

The application of communication networks within process control systems can offer real time "connection" to other plant functions which will reduce set up times, and an interface with management service functions including production scheduling, product design and quality assurance. While there are undoubtedly many industrial application areas in which the installation of a local area network can be justified on strictly financial grounds, the lack of standards means that there is no guarantee that compatible equipment will continue to be available for a given network. Progress is now being made, although slowly, towards the adoption of international standards. However, it seems likely that local area networks will not gain widespread acceptance in industrial control until such standards have been established [39] [40] [41] [42] [43] [44] [45].

6.4 STANDARDS FOR LOCAL COMPUTER NETWORKS

As we can observe from the market today, there are numerous types of local networks that developed by different companies. It is obvious that these products are independent from each other because individual company establishing, experimenting and connecting their own products. This is not a good sign as in the long run because the utility of a communication system will be a function of the number of different resources which can be addressed. Therefore, development of a standard for interfacing local networks, at the lowest physical level or higher levels of protocol, is essential.

There is an existing recommended standard for access to public switched networks, CCITT Recommendation X.25 with the title *interface between data terminal equipment (DTE) and data circuit-terminating equipment (DCE)* for terminals operating in the packet mode on public data networks. The X.25 standard incorporates several other lower level standards for physical connection (X.21) and line control. However, the internal protocols used by public networks are not specified, therefore, it is only an access protocol and does not guarantee any end-to-end service.

Also, the symbols and terminology used in local area networks are not well defined by international organizations, such as CCITT. Obviously, standardization in the field of local area networks is required in order to allow compatible equipments to be purchased from a variety of manufacturers and so provide maximum flexibility in the specification and implementation of industrial control systems, data processing systems or office automation systems.

6.5 OTHER DIRECTIONS FOR THE FUTURE

In addition to the above important aspects for future work, there are still many other topics associated with local networks awaiting further exploration, such as:

* Internetwork protocols.
* Measurement of a pattern of usage from a single machine in local networks.
* Self diagnostic program to troubleshoot the network system.

* Exploration of new transmission media, such as, fiber optics, infrared transmission.

This thesis represents only the prelimary work on design and implemention of the CFMA Priority Net, analysis of different approaches in LAN design, future trend of networks and some applications in this field. Clearly, the field of local networking is going to provide very fertile ground for many different kinds of research and system configuration. Of course, the most attractive issue of LAN is the market which has been predicted to break $200 million by 1986 including baseband and broadband shipments [46].

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To help in navigating through these references, the bibliography has been broken up into two major parts: the first half on local computer networks and the second half containing references on other relevant subjects. The bibliography is intended to be a comprehensive review of the literature in this area, and includes many additional reference which are not necessary cited in the main body of the text. Most of the listing are verified in mid-January 1982 by Architecture Technology Corp., Minneapolis, Minn. [46]

A GUIDE TO THE PRODUCTS WITH COMPANIES AND THEIR LITERATURE ON LOCAL COMPUTER NETWORK

This section of the bibliography provides a broad taxonomy for classifying work on local computer networks. In general, systems have been categorized according to their basic physical connectivity: partially connected network, stars, bus systems, etc.. The list also gives the speed of each network: low speed, defined as less than 1 Mbps; medium speed, up to 20 Mbps; and high speed, more than 20 Mbps.

Partially connected networks, store-and-forward

* The ARPANET itself by Defense Communications Agency, U.S.A -low speed.
[McQuillan & Walden, 1977]

* DECNET by Digital Equipment Corportion.
[Loveland, 1979]

* RPCNET in Pisa by IBM.
[Franchi, 1976]

Star Networks

* Octopus by Lawrence Livermore Laboratory.

[Fletcher, 1975]

* AT&T's Transaction Network Service by AT&T, U.S.A.

[Heffron & Snow, 1978]

* Sperry-Univac switch by Sperry Univac Corp..

[Moran & Starkson, 1975]

Ring and Loops

* The Cambridge Ring at Cambridge University, England - Medium speed.

[Saltzer and Clark, 1981]

[Hopper and Wheeler, 1979]

* Primenet by Prime Comupter - medium speed.

[Nelson & Gordon, 1978]

* Spider Network by Bell Labs. - low speed.

[Fraser, 1975]

Radio-based Approaches

* The ALOHA System at the University of Hawaii.

[Binder, 1975]

[Abramson, 1970]

* The Packet Radio Network in San Francisco Bay.

[Shoch and Stewart, 1979]

* Advanced Mobile Phone Service by Bell Labs. in Chicago.

[Hindin, 1979]

Multiaccess Bus Networks

* The Ethernet at Xerox Parc. - Medium speed.

[Metcalfe and Boggs, 1976]

[Shoch & Hupp, 1979]

* ENET and CNET at Queen Mary College - medium speed.

[Davison, 1978]

* Z-net by Zilog - medium speed.

[Benhamou and Estrin, 1981]

* Hyperchannel by Network System - high speed.

[Thornton, 1979]

* Fibernet at Xerox Parc - High speed.

[Rawson and Metcalfe, 1978]

* NBS at National Bureau of Standards - medium speed.

[Carpenter and Sokol, 1980]

* Fordnet at Ford Areospace - low speed.

[Biba and Yeh, 1979]

* Priority Ethernet at University of Tokyo - medium speed.

[Onoe, et al., 1978]

* Acknowledging Ethernet at Keio University - medium speed.

[Tokoro and Tamaru, 1977]

* Mitrix by Mitre - medium speed.

[Willard, 1974]

* CSMA/LWT at Mitre/Washington - medium speed.

[Wood, Holmgren and Skelton, 1979]

* Net/One by Ungermann-Bass - Medium speed.

[Davidson, 1982]

* Hyperbus by Network System - medium speed.

* Arcnet by Datapoint - medium speed.

* Comnet by Pragmatronics - low speed.

* Cluster/One model A by Nester System - low speed.

* Hinet by Digital Microsystems - low speed.

* Omninet by Corvus Systems - low speed.

REFERENCES ON RELATED TOPICS IN LOCAL AREA NETWORK

Network Product Suppliers

* AMD at Sunnyvale, Calif.

[Ethernet Components (VLSI, MOS, VLSI)]

* Aph Technological Consulting at Pasadena, Calif.

[Ethernet interface for the DEC LSI-11]

* Bridge Communications at Sunnyvale, Calif.

[High-level communications services Ethernet board]

* Canoga Data Systems at Canoga Park, Calif.

[Fiber optics systems]

* Codex at Mansfield, Mass.

[Network support products]

* Computer Energy (CEI) at Coleman, Wash.

[3270 Local network wiring products]

* Computrol at Ridgefield, Conn.

[Megalink, modems, Comptrol Systems]

* Concord Data Systems at Lexington, Mass.

[CCITT switching telephone network products, IEEE 802 token passing products]

* Datastream Communications at Santa Clara, Calif.

[Network access systems (T7 IBM gateway)]

* Envax Corp. at Irving, Texas.

[Envax 500 (intelligent box to interface an LCN to Telex/TWX/others)]

* Harris at Melbourne, Fla.

[A single chip military standard serial interface]

* Hewlett-Packard at Cupertino, Calif.

[HP 12050A fiber optic, HP-IB link]

* ITT at Roanoke, Va.

[Optic fiber digital modules]

* Intel at Santa Clara, Calif.

[Ethernet 432 based systems, Multibus boards, development systems]

* Interlan, Inc. at Chelmsford, Mass.

[LCN controller boards and software]

* Lee Data at Eden Prairie, Minn.

[Coax Eliminator (for 3270-based products)]

* Masstor Systems at Sunnyvale, Calif.

[Shared VSS (virtual storage system)]

* Mostek at Carrolition, Texas.

[Ethernet components (VLSI, MOS-VLSI)]

* MuSYS at Tustin, Calif.

[NET/82 S-100 Z80A single board computer to provide networking]

National Semiconductor at Sunnyvale, Calif.

[LC-8545 intelligent communications controller board]

* TCL at Santa Clara, Calif.

[Plug-compatible Ethernet (PCE) transceiver]

* 3COM at Mountain View, Calif.

[Plug-compatible Ethernet (PCE) transceiver]

* Valtec Corp. at West Boylston, Mass.

[Fiber optic data transmission links]

* Western Digital at Irvine, Calif.

[1 MBps token passing LSI chip and chips supporting the X.25 standard]

Related Topics in Local Area Network

* Communication Media Cost Comparison.

[W.R. English, 1980]

* An Introduction to Local Area Networks.

[Clark, Pogran and Reed, 1978]

* Introduction to Local Area Network.

[Digital Equipment Corporation, 1982]

* Ethernet designer's guide.

[R. Crane, 1982]

* Ethernet Specification by Xerox.

* Practical Consideration in Ethernet Local Network Design.

[Crane and Taft, 1982]

* Four-level Pulse Width Modulation for fiber-optic Communications.

[Goud and Englefield, 1982]

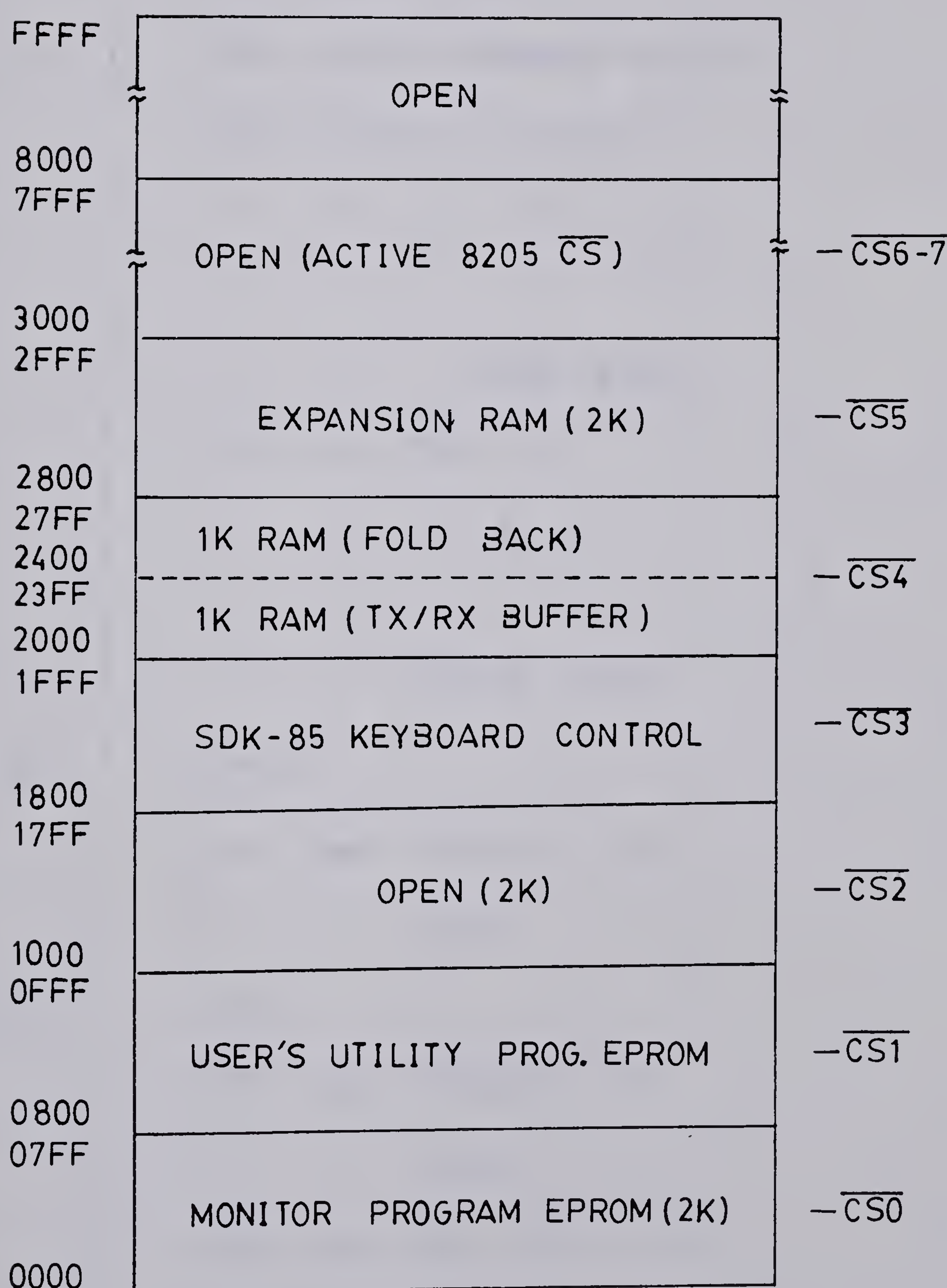
* Error Probability for multilevel PAM Transmission with Intersymbol interference.
[Biglieri, 1982]

* Quantised Pulse Duration Modulation - a new multilevel digital Transmission technique.
[Chung and Ingram, 1982]

* A gateway development system.
[Shepherd and Corcoran, 1982]

APPENDIX I

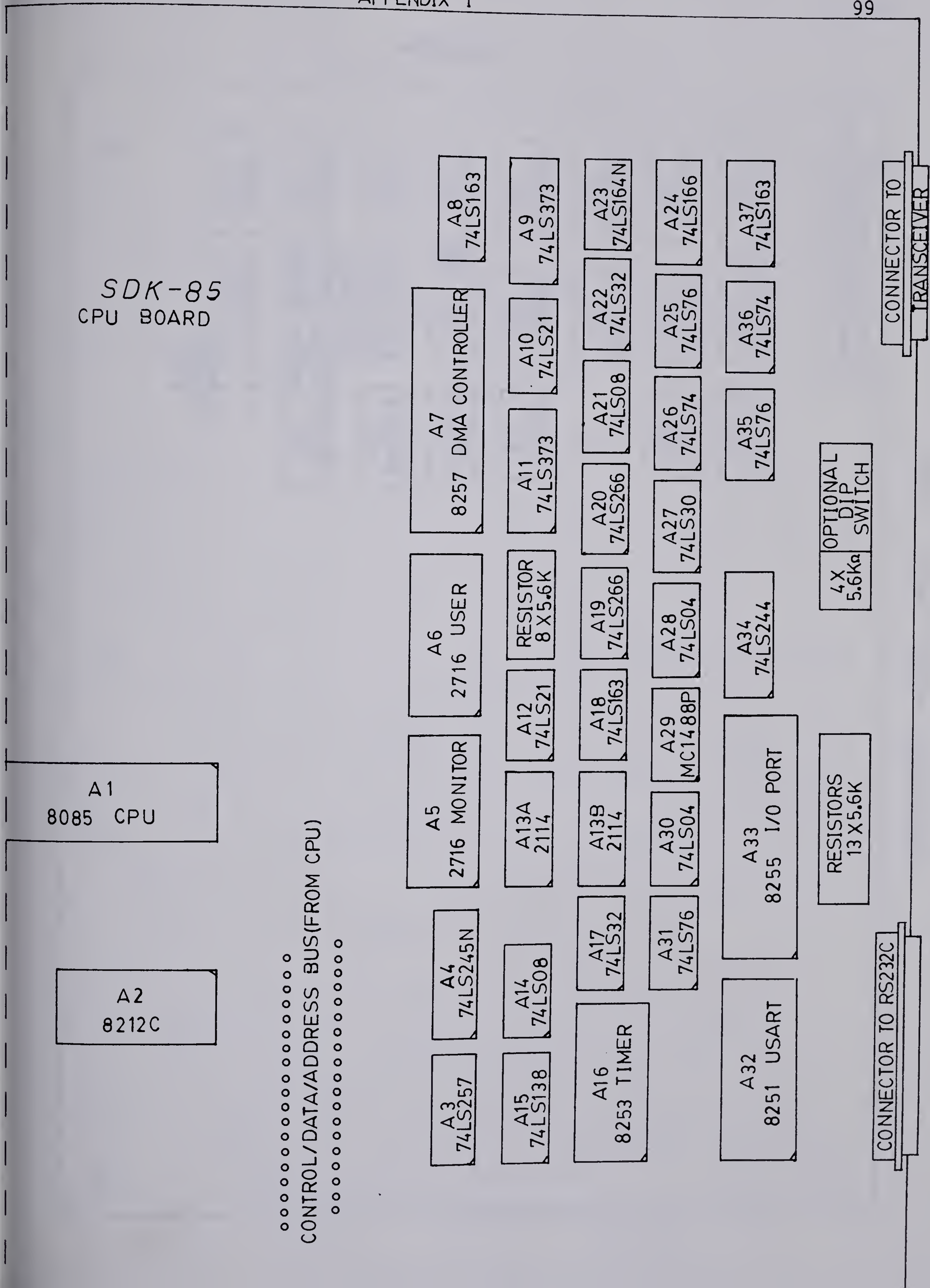
CONTROLLER MEMORY MAP (SDK-85)



APPENDIX I

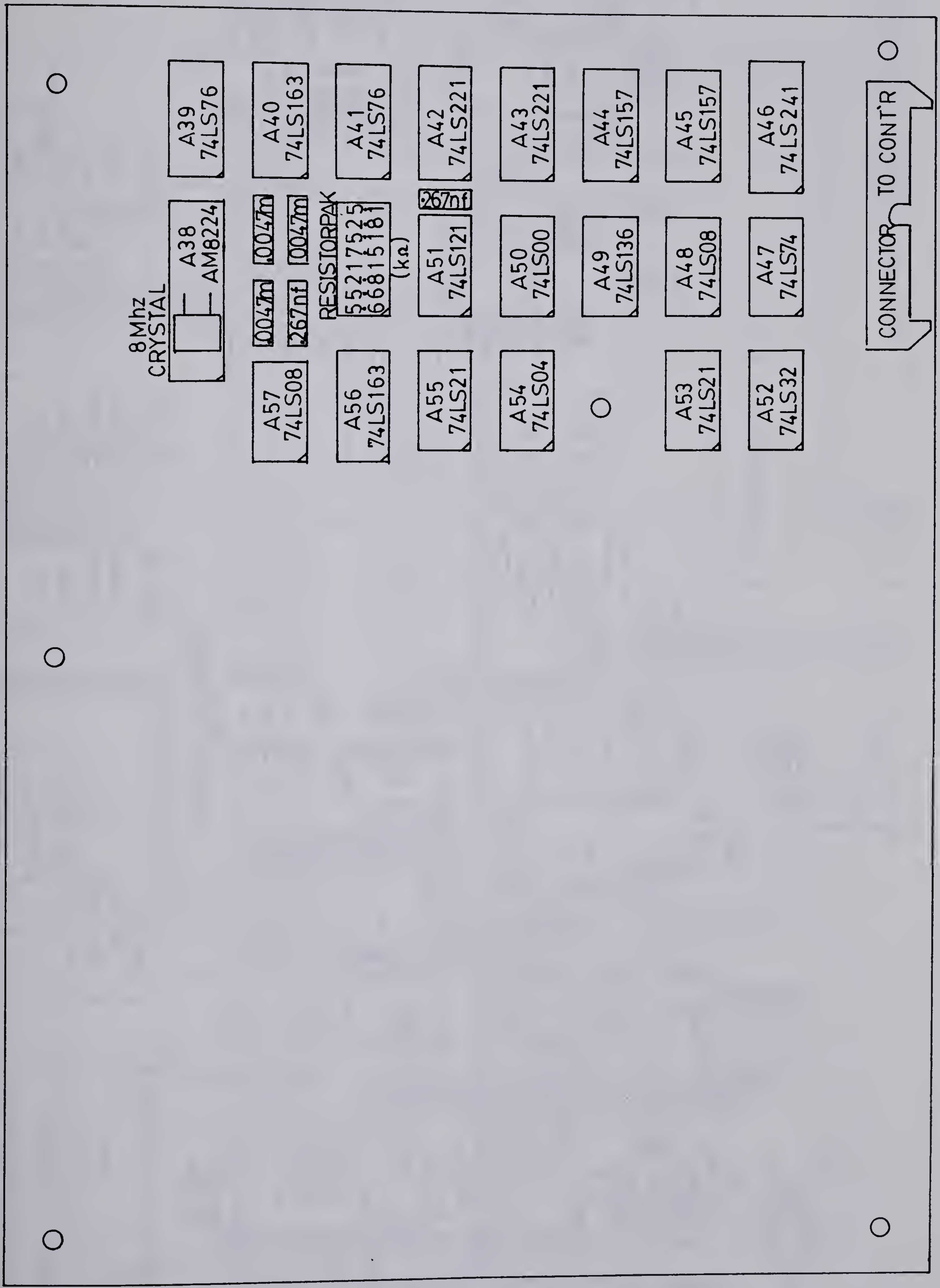
CONTROLLER I/O PORT MAP (SDK-85)

PORT	FUNCTION
40	OPEN
41	OPEN
42	8251 USART - DATA
43	8251 USART - COMMAND/STATUS
44	8253 TIMMER - COUNTER 0
45	" " " 1
46	" " " 2
47	" " - MODE WORD
48	8255 I/0 - PORT A
49	" " " B
4A	" " " C
4B	" " - CONTROL WORD
4C - 4F	OPEN
50	8257 DMA ADDRESS - CH. 0
51	" " COUNT - "
52 - 55	OPEN
56	8257 DMA ADDRESS - CH.3
57	" " COUNT - "
58	8257 DMA MODE SET/STATUS
59 - 5F	OPEN
>60	N.C.

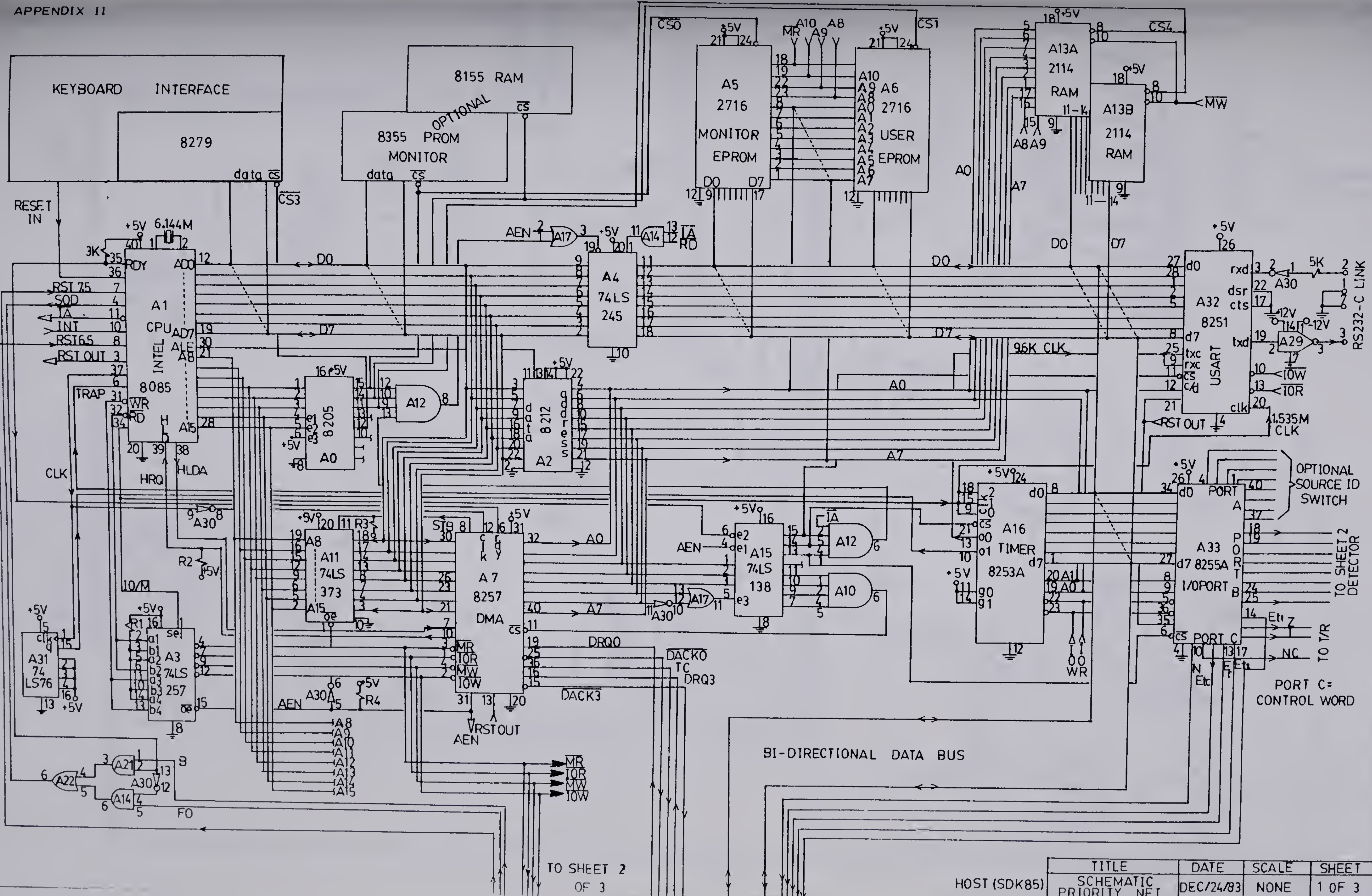


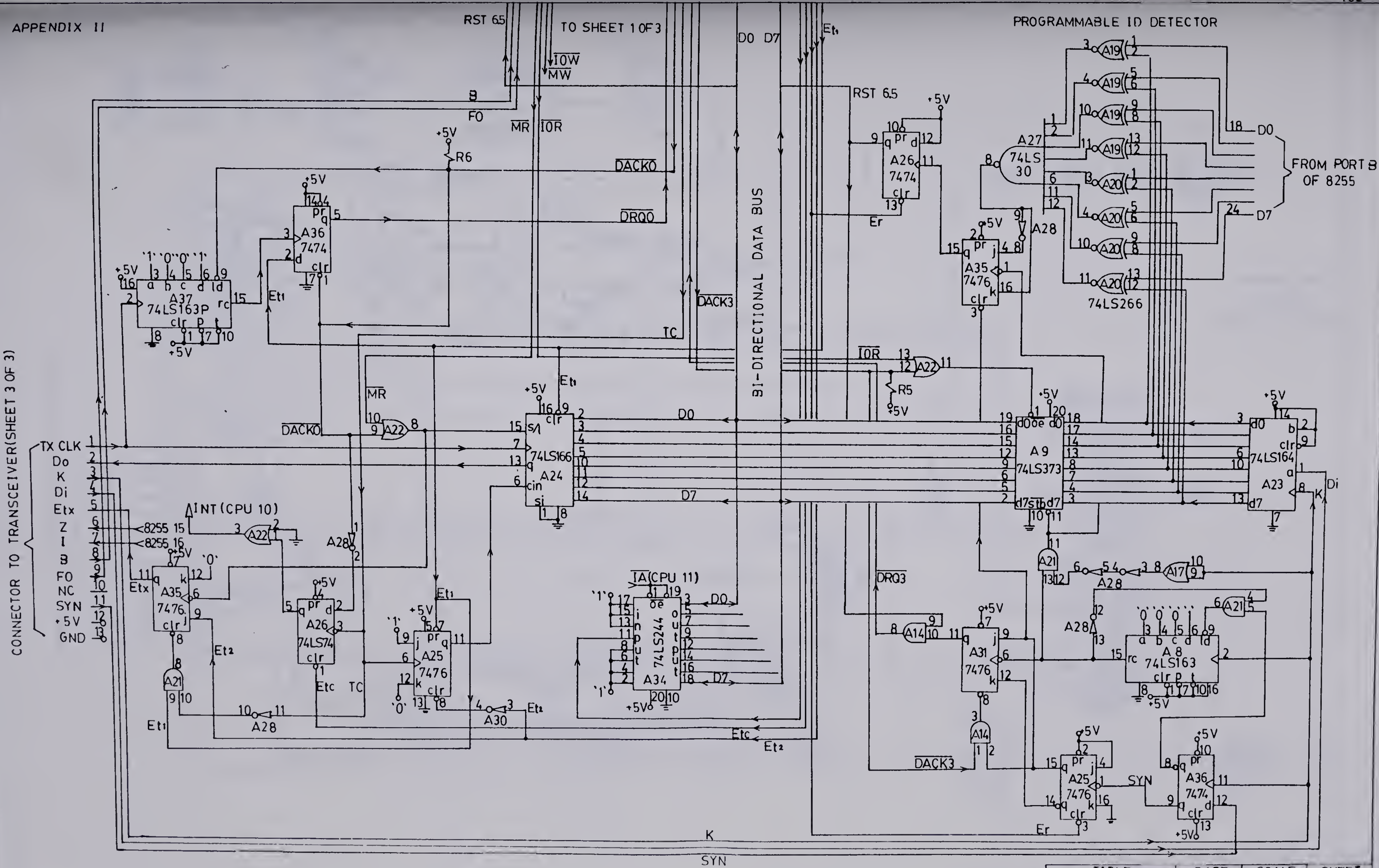
CONTROLLER BOARD CIRCUIT LAYOUT

APPENDIX I



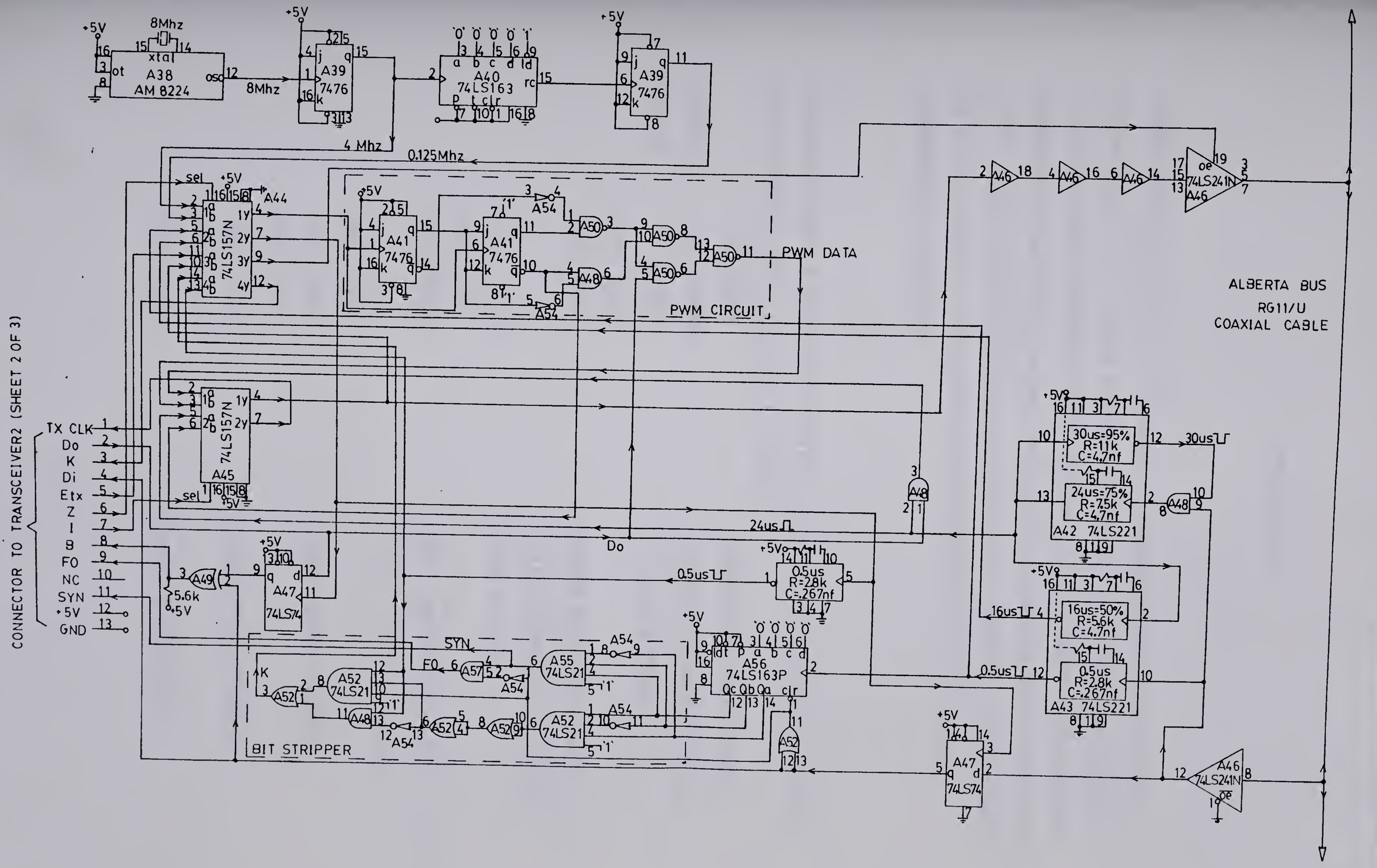
TRANSCEIVER BOARD CIRCUIT LAYOUT


KEYBOARD INTERFACE
8279
8155 RAM
OPTIONAL
8355 PROM MONITOR
A5 2716 MONITOR EPROM
A6 2716 USER EPROM
A13A 2114 RAM
A13B 2114 RAM
RESET IN
A1 CPU INTEL 8085
6.144M
A4 74LS 245
A0 8205
A2 8212
A32 8251 USART
RS232-C LINK
1.535M CLK
96K CLK
A11 74LS 373
A7 8257 DMA
A15 74LS 138
A16 TIMER 8253A
A33 8255A I/O PORT
OPTIONAL SOURCE ID SWITCH
TO SHEET 2 DETECTOR
TO T/R
NC
PORT C= CONTROL WORD
A3 74LS 257
A31 74 LS76
BI-DIRECTIONAL DATA BUS
TO SHEET 2 OF 3
HOST (SDK85)
TITLE
SCHEMATIC PRIORITY NET
DATE
DEC/24/83
SCALE
NONE
SHEET
1 OF 3



TITLE	DATE	SCALE	SHEET
SCHEMATIC	DEC/24/83	NONE	2 OF 3

CONTROLLER



TRANSCEIVER

TITLE	DATE	SCALE	SHEET
SCHEMATIC PRIORITY NET	DEC/29/83	NONE	3 OF 3

APPENDIX III

```
;THESE SUBROUTINES ARE DEVELOPED TO DEMONSTRATE THE FLEXIBILITY
;OF PRIORITY NET, IT IS UP TO PEOPLE HOW TO USE THESE SUBROUTINES
;TO DEVELOPE DIFFERENT ACCESS SCHEME TO IMPLEMENT THE VARIOUS
;FORMS OF CFMA BUS NETWORK, PROGRAM / HARDWARE WERE DEVELOPED
;BY W. FUNG UNDER SUPERVISION OF PROF. D. ZISSOS/K.A. STROMSMOE
;IN U. OF ALBERTA, THESE PROGRAMS WERE WRITTEN IN INTEL 8085
;ASSEMBLER LANGUAGE.
;
;
;PROGRAM FOR RX BROADCAST MODE, STATION'S ID NOW FORCED TO 00H
;AND THE RX BUFFER LOCATED AT 2100H.
            ORG 800H            ;PROGRAM START AT 800H
CONBUF      EQU 20BFH           ;CONTROL WORD REGISTER
OWNID       EQU 20B9H           ;STATION'S OWNID
            MVI A,00H
            OUT 49H             ;STORE BROADCAST MODE ID TO
                                PROGRAMMABLE DETECTOR
            MVI A,80H           ;DMA RX INIT
            OUT 57H
            MVI A,40H           ;DMA UPPER BYTE COUNT + B6 TO
                                INDICATE WRITE MODE
            OUT 57H
            MVI A,00H           ;DMA LOWER ADDRESS
            OUT 56H
            MVI A,21H           ;DMA UPPER ADDRESS
            OUT 56H
            MVI A,10H           ;ENABLE RECEIVER
```

```
OUT 4AH
MVI A,7AH        ;MASK ALL INTERRUPT EXCEPT
                 RST7.5
SIM
EI
MVI A,48H
OUT 58H
HLT              ;WAIT FOR INTERRUPT BY ENDING
                 FLAG
```

```
;PROGRAM FOR TX BROADCAST MODE, TX BUFFER STARTED AT 2300H,
;REMEMBER TO END YOUR MESSAGE BY INCLUDE ENDING FLAG AT THE
;END IN ORDER TO RUN THIS PROGRAM.  PLEASE ENABLE THE RECEIVING
;STATIONS BEFORE EXECUTING THIS.
        ORG 850H            ;PROGRAM START AT 850H
        LXI H,22FFH         ;LOAD THIS BYTE WITH BROADCAST
                            MODE ID 00
        MVI A,00H
        MOV M,A             ;STORE IT IN MEMORY
        DCX H
        MVI A,7FH           ;LOAD SYNC BYTE
        MOV M,A
        MVI A,0CH           ;ENABLE INTERNAL FAST CLOCK
        OUT 4AH
        MVI A,0DH           ;DMA BYTE CONT
        OUT 51H
        MVI A, 80H          ;DMA UPPER BYTE COUNT + B7 TO
                            INDICATE READ
        OUT 51H
        MVI A,0FFH          ;DMA LOWER ADDRESS
        OUT 50H
        MVI A,22H
        OUT 50H             ;DMA UPPER BYTE COUNT
        MVI A,0ADH          ;CONTROL WORD TO ENABLE TX
        OUT 4AH
        MVI A,7FH           ;MASK ALL INTERRUPT
        SIM
        EI
        MVI A,41H
        OUT 58H             ;FINAL DMA ENABLE WORD
```

```
        HLT                     ;WAIT TO INTERRUPT BY END OF
                                TRANSMISSION FLAG
```

```
;THIS IS THE DEMONSTRATION SUBROUTINE TO RECEIVE MESSAGE
;ADDRESSED TO INDIVIDUAL STATION(RX ADDRESSING MODE). PROGRAM
;STARTS AT 0900H AND THE RX BUFFER LOCATED AT 2100H. REMEMBER
;TO LOAD YOUR OWNID INTO 20B9H FIRST.
            ORG 900H                ;PROGRAM START AT 900H (ALSO
                                    THE RX ENTRY POINT FOR RST 6
                                    INTERRUPT)
            LXI H,2100H             ;CLEAR MEMORY WITH FF
            MVI A,10H               ;NO. OF BYTE TO CLEAR
            MVI B,0FFH              ;FILL WITH FF
ZZZ         MOV M,B                 ;COPY B TO MEMORY
            INX H
            DCR A
            JNZ ZZZ
            LXI H,OWNID             ;LOAD YOUR OWNID TO
                                    PROGRAMMABLE DETECTOR
            MOV A,M
            OUT 49H
            MVI A,80H               ;DMA LOWER BYTE COUNT
            OUT 57H
            MVI A,40H               ;DMA UPPER BYTE COUNT
            OUT 57H
            MVI A,00H
            OUT 56H                 ;DMA L ADDRESS
            MVI A,21H               ;DMA U ADDRESS
            OUT 56H
            MVI A,10H               ;ENABLE RX MODE
            OUT 4AH
            MVI A,7AH               ;MASK OFF INTERRUPT EXCEPT
                                    RST7.5
            SIM
```

```
EI
MVI A,48H           ;FINAL ENABLE WORD FOR DMA
OUT 58H
HLT                 ;WAIT TO BE INT BY ENDING FLAG
```

;THIS IS CALLED TX ADDRESSING MODE OF PRIORITY NET , TX BUFFER
;LOCATED AT 2300H. THIS DEMONSTRATION SUBROUTINE START AT
;0950H. FIRST BYTE MUST BE DESTINATION ID FOLLOWED BY MESSAGE,
;ENDED BY ENDING FLAG.

```
        ORG 950H            ;TX PROGRAM START AT 950
        LXI H,22FFH         ;FORM THE TX FORMAT
        MVI A,7FH
        MOV M,A
        MVI A,0CH           ;START THE INT FAST CLOCK FIRST
        OUT 4AH
        MVI A,0CH           ;LOAD DMA LOWER BYTE COUNT
        OUT 51H
        MVI A,80H           ;LOAD DMA UPPER BYTE COUNT +
                            READ BIT AT B7
        OUT 51H
        MVI A,0FFH          ;LOAD DMA LOWER ADDRESS
        OUT 50H
        MVI A,22H           ;LOAD DMA UPPER ADDRESS
        OUT 50H
        MVI A,0ADH          ;LOAD FINAL CONTROL WORK TO
                            ENABLE TX
        OUT 4AH
        MVI A,7FH           ;MASK OFF ALL INTERRUPT
        SIM
        EI                  ;ENABLE END OF TRANSMISSION
                            INT., THEN JMP BACK TO MON
        MVI A,41H
        OUT 58H             ;FINAL ENABLE SIGNAL TO DMA
        HLT
```

```
;THIS IS THE SUBROUTINE TO RECEIVE HANDSHAKE REQUEST FROM
;TRANSMITTING STATION, AND GENERATE THE RST6.5 INTERRUPT IF
;THE DESTINATION ID MATCHED TO IT'S OWNID.  THE RX BUFFER
;LOCATED AT 2100H, REMEMBER TO STORE YOUR OWN STATION ID AT
;LOCATION 2000H BEFORE STARTING THIS PROGRAM.
            ORG 0A00H            ;PROGRAM START AT A00H
            LXI H,OWNID          ;STORE YOUR OWNID TO
                                 PROGRAMMABLE ID DETECTOR
            MOV A,M
            OUT 49H
            MVI A,7DH            ;MASK ALL INTERRUPT EXCEPT
                                 RST6.5
            SIM
            EI
            LXI H,CONBUF         ;LOAD CONTROL WORK TO
                                 REGISTER
            MVI A,10H            ;JUST TO ENABLE RX CIRCUIT
            MOV M,A
            OUT 4AH              ;ENFORCE THIS CONTROL WORD
            HLT                  ;WAIT FOR YOUR OWNID TO GEN.
                                 RST6.5 INT.
```

```
;THIS IS THE ENTRY POINT FOR RST6.5 INT..  BY TESTING BIT 6 OF
;CONTROL WORD, WE CAN DET.  WHETHER THIS IS CAUSED BY RESPONSE
;OR STATION'S ID.
                ORG 0A20H              ;ENTRY POINT FOR RST6.5
                                       INTERRUPT
RST65           LXI H,CONBUF           ;LOAD CONTROL WORD FROM
                                       REGISTER
                MOV A,M
                NOP
                ANI 40H                ;CHECK THIS FLAG IS SET OR NOT
                JNZ 0000H              ;IF NOT ZERO THEN YOU ARE THE
                                       MASTER STATION
                LXI H,OWNID            ;SET UP THE RESPONSE TX
                                       PATTERN
                DCX H
                MVI A,7FH              ;LOAD THE SYN BYTE AS 1 ST
                MOV M,A
                MVI A,0CH
                OUT 4AH                ;SET THE INTERNAL FAST CLOCK
                                       FIRST
                MVI A,02H              ;LOAD LOWER BYTE COUNT
                OUT 51H
                MVI A,80H              ;LOAD UPPER BYTE COUNT + 7 AS
                                       READ MODE
                OUT 51H
                MVI A,0B8H             ;LOAD DMA LOWER ADDRESS
                OUT 50H
                MVI A,20H              ;LOAD DMA UPPER ADDRESS
                OUT 50H
                MVI A,2DH              ;CONTROL WORD JUST TO ENABLE
                                       TC FLAG/TX CIRCUIT
```

```
              OUT 4AH
              MVI A,7FH
              SIM                   ;JUST ENABLE RST 6 FOR END OF
                                    TXSION
              EI
              MVI A,41H             ;FINAL ENABLE SIGNAL FOR DMA
              OUT 58H
              HLT                   ;WAIT FOR INT TO JUMP TO RST 6 at
                                    0A80H
                                    ;;
                                    ;;
              ORG 0A80H             ;TX AND RX ENTRY POINT FOR RST
                                    6
RST6          LXI H,CONBUF          ;LOAD CONTROL REGISTER VALUE
              MOV A,M
              ANI 40H               ;CHECK WHETHER YOU ARE TX OR
                                    NOT
              JNZ 0AA0H             ;NOT ZERO THEN YOU ARE TX
              JMP 0900H             ;ZERO, THEN YOU ARE RX, JUMP TO
                                    ADDRESSING RX MODE
```

```
;HERE IS TX ENTRY POINT FOR RST 6 INTERRUPT
          ORG 0AA0H          ;PROGRAM START AT 0AA0H
          MVI A,10H          ;SEND CONTROL WORD TO ENABLE
                             RECEIVE
          OUT 4AH            ;
          MVI A,7DH          ;MASK OFF ALL INTERRUPT
                             EXCEPT RST6.5
          SIM
          EI
          HLT                ;NOW WAIT FOR RESPONSE FROM
                             YOUR RX,IT IS RST6.5
```

;THIS IS THE SUBROUTINE PROGRAM TO GENERATE THE HANDSHAKE
;REQUEST ONCE THE STATION SEIZES THE BUS, AND THEN WAIT FOR
;THE RESPONSE FROM RX STATION. THIS TX (MASTER) HANDSHAKE
;MODE PROGRAM STARTS AT 0B00H.PLEASE STORE YOUR DESTINATION
;ID AT 2300H FOLLOWED BY MESSAGE, ENDED BY ENDING FLAG.

```
        ORG 0B00H           ;START AT 0B00H
        LXI H,2300H
        MOV A,M             ;LOAD DESTINATION ID TO
                            PROGRAMMABLE DETECTOR
        OUT 49H
        DCX H
        MVI A,7FH
        MOV M,A             ;LOAD 1 ST AS SYN BYTE
        MVI A,0CH           ;START INT FAST CLOCK FIRST
        OUT 4AH
        MVI A,02H
        OUT 51H             ;DMA TX INIT
        MVI A,80H
        OUT 51H
        MVI A,0FFH
        OUT 50H
        MVI A,22H
        OUT 50H
        LXI H,CONBUF        ;LOAD CONTROL REGISTER
        MVI A,6DH           ;CONTROL WORD
        OUT 4AH
        MOV M,A
        MVI A,7FH           ;MASK ALL INT EXCEPT INT
        SIM
        EI
        MVI A,41H           ;FINAL ENABLE WORD FOR DMA
```

```
        OUT 58H
        HLT                     ;WAIT FOR RESPONSE FROM RX
                                STATION
;; NOW IT IS UP TO YOU WHETHER YOU WANT TO TX OR NOT.
```

```
;HERE IS THE RX CONTENTION DEMON.  RUN, REMEMBER TO TYPE YOUR
;OWNID IN LOCATION 20B9H BEFORE START PROGRAM.  THIS PROGRAM
;WILL LATCH YOUR OWNID TO SHIFT REGISTER 74LS166 (A24), AND
;THEN SHIFT OUT BY THE DUMMY ID CLOCK (LEADING EDGE) TO
;CONTENT THE BUS.
                ORG 0C00H
                MVI A,0CH          ;PROGRAM START AT 0C00H, FIRST
                                   LOAD INTERNAL CLK
                OUT 4AH
                MVI A,01H          ;DMA LOWER BYTE COUNT
                OUT 51H
                MVI A,80H          ;DMA UPPER BYTE COUNT
                OUT 51H
                MVI A,0B8H         ;DMA LOWER ADDRESS
                OUT 50H
                MVI A,20H
                OUT 50H            ;DMA UPPER ADDRESS
                MVI A,85H          ;CONTROL WORD
                OUT 4AH
                MVI A,7FH          ;DISABLE ALL THE INTERRUPT
                SIM
                DI
                MVI A,41H          ;ENABLE WORD FOR DMA
                OUT 58H
                NOP
                NOP
                MVI A,0BH
                OUT 4AH            ;CHANGE RX INTO RX CONTENTION
                                   MODE
                MVI A,7FH          ;DELAY TO WAIT FOR BACK OFF
DELAY           DCR A
```

```
JNZ DELAY
JMP 0000H                ;END OF DELAY, THEN JMP BACK
                         TO MONITOR
```

```
;HERE IS TX CONTENTION PROGRAM FOR PRIORITY NET.  THIS PROGRAM
;PROVIDING DUMMY ID FOR THE BUS TO SYNCHRONIZE REST OF THE
;RECEIVING STATIONS TO CONTENT.  THE UPPER RST7.5 INTERRUPT
;WILL BE ENABLED IF THERE IS ANY BACK OFF SIGNAL DETECTED.
                ORG 0C50H                   ;PROGRAM START AT 0C50H
                MVI A,0FH                   ;CONTROL WORD FOR TRANCEIVER
                OUT 4AH
                MVI A,0FBH                  ;JUST ENABLE UPPER RST7.5
                                            INTERRUPT
                SIM
                EI
                HLT                         ;WAIT FOR INTERRUPT BY BACK
                                            OFF
;;
;;
;;
;               LIST DBG
                END
```